REMOTE SENSING APPLICATIONS IN FORESTRY

MULTISTAGE, MULTIBAND AND SEQUENTIAL
IMAGERY TO IDENTIFY AND QUANTIFY
NON-FOREST VEGETATION RESOURCES

by

Richard S. Driscoll
Richard E. Francis

Rocky Mountain Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture

Annual Progress Report   30 September 1971

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California
A Coordination Task Carried Out in Cooperation with
The Forest Service, U. S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

This is the fourth annual progress report to assess the merits of aerial and space photography and multispectral scanner imagery for the interpretation and analyses of nonforest (shrubbery and herbaceous) native vegetation. The research for this reporting period was devoted primarily to analysis and recognition processing of multispectral scanner imagery for plant community classification in cooperation with the IROL at the University of Michigan. Also, interpretations of various film/filter/scale aerial photographs taken by NASA's RB57F were mostly completed. Data analyses and manuscript preparation of research on microdensitometry for plant community and component identification and remote estimates of biomass were completed.

Preprocessing of the scanner signals had to be done to eliminate a serious scan angle effect. This effect, defined as a third order polynomial, was believed to have been caused primarily by bidirectional reflectance of the target scenes and minimally by atmospheric attenuation of the target signal. Optimum channel selection, among the 12 channels of data available, identified six as providing the best information about 12 vegetation types and two nonvegetation categories. Final processing of the normalized data provided acceptable recognition results of generalized plant community types: Forested, grassland and hydrophyllic communities. Serious errors occurred with attempts to classify some of the specific community types within the grassland areas. Additional

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analyses need to be done considering the convex mixtures concept of effects of different amounts of scene materials, i.e. live plant cover, exposed soil and plant litter cover, on apparent scene radiances to improve plant community classification.

Underexposure and nonuniform exposure of film/filter combinations not previously used at the Manitou test site and flown by the RB57F limited discrete interpretation regarding optimum combinations of film type/photoscale for plant community classification. In general, color infrared (2443 + 15 filter) was better than regular color for this purpose. A photoscale of 1:53,000 has the most value for refining multiple sampling techniques. Information gain using a 1:104,000 photoscale would be minimal for community classification and quantification, at least in areas similar to the Manitou test site.

Microdensitometry with color infrared aerial photography does show promise for automated discrimination of plant communities and components at photoscales ranging from 1:800 to 1:139,000. Identification accuracy should be improved using linear discriminate analyses of data from seasonal sequential photography.

Standing green crop biomass and its reciprocal, oven dry component, were significantly correlated to color infrared photo image density determined by microdensitometry. Image density of six classes of standing crop seeded big bluegrass was measured with a GAF microdensitometer using a green filter. The correlation coefficient between standing crop (y) and image density (x) was significant (P = .01) in all cases and greater than 0.80. The relationship was expressed as a simple linear function: $y = a + b(x)$.

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ACKNOWLEDGMENTS

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MULTISTAGE, MULTIBAND AND SEQUENTIAL IMAGERY

TO IDENTIFY AND QUANTIFY NONFOREST VEGETATION

by

Richard S. Driscoll

INTRODUCTION

Nonforest vegetation, as used in this report, refers to native
vegetation other than trees and includes exotic species used for
special purposes. These special situations include vegetation
improvements for food and cover for wildlife and domestic livestock
or for protection of heavily used areas such as recreation sites. It
does include that vegetation which occurs as understory in forested
ecosystems. We are not especially concerned with the individual
trees or tree stands except in relation to influences on understory
species.

There are approximately 1.2 billion acres of land in the
conterminous United States classed as forest and range ecosystems.
These lands include the high mountain wilderness areas of the West
as well as areas adjacent to highly populated metropolitan
environments. This land area is shrinking through urban area expansion,
the development of high-density recreation areas away from the metro-
politan areas, and the development of completely new communities.
Some of the area is fragile, such as the desert and high-mountain
alpine and subalpine environments of the West. Much of the landscape

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is complex with highly variable topo-edaphic and consequent vegetation systems occurring over short distances. These conditions make it difficult to unlock the interrelationships of land use demands. Frequent decisions must be made not only for planning land use but also for determining the effects of different kinds of land use on the total ecosystem. Remote sensors, with their rapid data gathering capabilities, provide real-time information for these decisions. We need to identify the kinds of data various sensors can provide about native vegetation and how such data can be most effectively analyzed and interpreted to assist in land use planning, development and management.

This is the fourth annual progress report detailing research undertaken since October 1970. Earlier reports (Driscoll and Reppert 1968; Driscoll 1969; Driscoll and Francis 1970) summarized the importance of the problem regarding detection, identification and measurement of herbaceous and shrubby vegetation using aerial and space photographs of those resources. These reports detailed research results on use of color and color infrared aerial photographs for identifying individual plant species and communities. Also included were results on use of a multiple sampling procedure for plant community classification and quantification using space (Apollo 9) and supporting aircraft photographs. Preliminary results for estimating herbaceous standing crop using large-scale color infrared aerial photographs and microdensitometry were included in our 1970 Annual Report. These reports have identified some potential applications

for use of aerial and space photographs for land use planning and management decisions although additional research is needed, especially in developing and testing sampling theory and techniques, before detailed operational procedures are defined.

Primary emphasis during the current reporting period has been on data analyses and summarization for manuscripts. The first part of this report describes multispectral processing and assessment of imagery taken July 29, 1970, by the University of Michigan's multi-spectral system. Also included in this section is an assessment of the photographic imagery taken on July 21, 1970, by the RB57F aircraft.

The second section of the report deals with other remote sensing research we have done that has been operationally financed partly by our NASA contract and partly by the Forest Service. This work includes: (1) Estimation of herbaceous standing crop with aerial photographs and microdensitometry, and (2) plant species and land classification with aerial photographs and microdensitometry.

The research described in both sections will coalesce to provide needed coefficients for understanding, through modeling, the structure and function of ecosystems using data from remote sensors.

THE STUDY AREAS

Data for the multispectral scanner and RB57F tests were obtained from the Manitou test site (NASA Site 242) (Figure 1). This area is designated as one of three major test sites for our proposed ERTS-A and Skylab experiments in cooperation with the Forest Remote Sensing

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Figure 1   The Manitou test site (Site 242).   The Manitou Experimental Forest,
a multidisciplinary research area maintained by the Rocky Mountain Forest and
Range Experiment Station, is located specifically on either side of the drain-
ageway between the two water bodies in the center of the photograph.   The
majority of our research is located in this area.   This photo was made from
IR color transparency from the NASA RB57F Mission 139; scale 1:104,000.

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Project, Pacific Southwest Forest and Range Experiment Station.
Current research at Manitou including our remote sensing work, is
multidisciplinary among several Forest Service research projects.
Consequently, information trade-off provides us with a significant
amount of ground truth we would otherwise not be able to accumulate.

Information obtained for our other research was obtained at or
near our Black Mesa, Kremmling and McCoy areas in addition to Manitou.
Detailed descriptions of all study areas have been defined in the
1968 and 1969 annual reports.

SECTION I

MULTISPECTRAL AND HIGH FLIGHT (RB57F) EXPERIMENTS

PROCEDURES

Ground Data

Ground truth for both of these experiments was obtained simul-
taneously since the objectives were similar, viz. discrimination of
native plant communities. The specific objective of the multispectral
experiment was to optimize multispectral channel data to determine
the best channel or channels for discrimination among nine different
herbaceous and shrubby plant communities and four different forested
communities. The specific objective of the high flight experiment
was to evaluate several film/filter combinations and photoscales not
previously used in the Manitou area for detecting and identifying
the same plant communities.

Immediately prior to the data missions, detailed mapping of the plant communities was completed. This mapping was based on current aspection of the plant communities and the relative composition of the communities regarding similarity of plant species components throughout the mapping unit. Medium-scale (1:8,000) color infrared mapping photographs flown approximately 6 weeks prior to the data missions were used in conjunction with detailed ground search. Each mapping unit represented a specific community type.

Plant species abundance was determined for each community type within 2 weeks of the missions. Abundance was based on a 5-point rating scheme ordered from very abundant to rare (Oosting 1956). At the same time, percent plant foliar cover, percent bare soil surface and percent plant litter cover of the soil surface of each of the plant communities were estimated. Such estimations were made by sampling with 3x3-foot sample plots (Figure 2) located by restricted random fashion throughout the community types. This plot size was related to the equivalent resolution element to be "seen" by the scanners at the lowest planned flight altitude for representation of the component mixtures of scene radiance. Plots 9 feet square were used at each sampling location to provide data directly related to the equivalent resolution element at the higher scanner flight altitude.

Considering the forested communities, ground cover sampling was restricted to land surface visible from above without interference from the tree canopy. All ground truth and sensor data were obtained at a time when most plant species were actively growing to offer the

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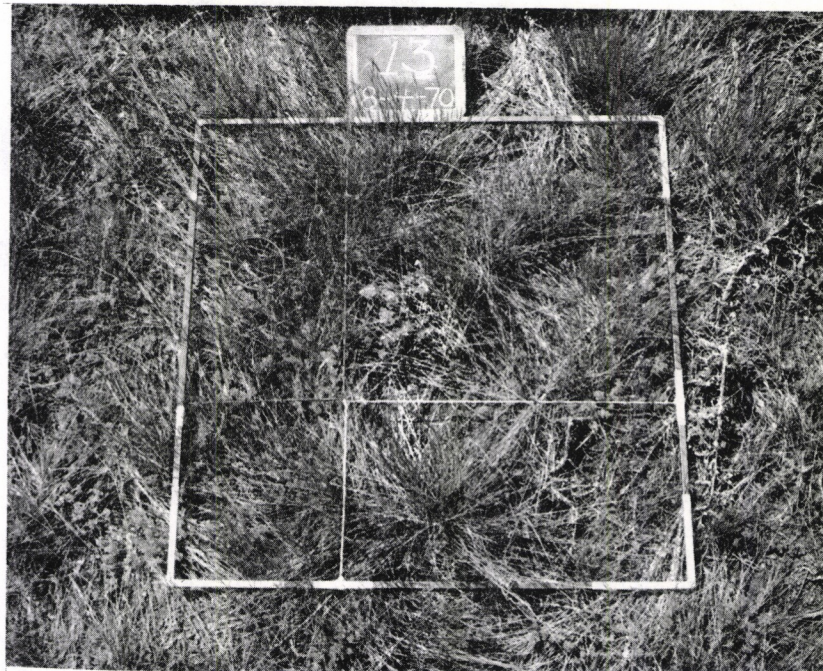
<u>Figure 2</u> Ground plots measuring 3 feet on a side were used to estimate
percent foliar cover, percent bare soil surface and percent plant litter
cover of the soil surface for each of the plant communities used for
multispectral recognition processing. This plot size represented the
equivalent resolution element for the 1,000-foot flight altitude.
Plots 9x9 feet at the same location were used to obtain ground data
related to the equivalent resolution element at the 3,000-foot altitude.

best opportunity for discrimination considering a single data mission period. This decision was based on interpretation of seasonal aerial photographs taken during previous years as well as detailed phenological knowledge of the Manitou area based on previous research. The mapping units and a brief description of their characteristics are listed in Table 1. Also included are four nonvegetation categories which constituted inclusions within the mapping units but which could possibly be discriminated in the multispectral analyses.

In addition, near vertical ground photos were taken from a stepladder within a representative area of each plant community type using color film (35mm Kodacolor-X) and color infrared (70mm and 35mm Ektachrome Infrared, Type 8443). These photos were used in conjunction with aerial photos and quantitative ground data for selecting and defining training samples for processing the scanner imagery.

Aerial Data

Multispectral (Mission M-19). All multispectral data collection was performed by the University of Michigan's multispectral scanning system on July 28 and 29, 1970. This system consisted of two double-ended optical mechanical scanners. Imagery requested included data records in 12 discrete spectrometer channels in the visible and near infrared, three intermediate infrared channels and two thermal bands (Table 2). Operating simultaneously with the scanner system were three aerial cameras: (1) K-17 loaded with Super 2 film with a K-2 Star filter;

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Table 1. Generalized description of vegetation mapping
units and landscape class inclusions

		% Soil Surface Cover		
Mapping Unit	Brief Description	Plant Foliage	Plant Litter	Bare Soil
1	Recently logged ponderosa pine (Pinus ponderosa) forest; mountain muhly (Muhlenbergia montana) and Arizona fescue (Festuca arizonica) dominant herbaceous vegetation	40.3	53.4	6.3
2	Mature ponderosa pine forest, mountain muhly and pussytoes (Antennaria spp.) dominant herbaceous species	29.1	54.6	16.3
3	Dense natural ponderosa pine regeneration; crown closure nearly 80 percent; forest floor primarily pine needle litter	8.0	91.0	1.0
4	Dense planted ponderosa pine, crown closure nearly 80 percent, herbaceous understory primarily mountain muhly	31.2	57.7	11.1
5	Seeded crested wheatgrass (Agropyron desertorum)	27.7	51.4	20.9
6	Seeded big bluegrass (Poa ampla)	19.2	72.4	8.4
7	Native grasslands; no tree or shrub components; Arizona fescue and mountain muhly were generally the most conspicuous species; other herbaceous species more prominent locally; generally the community was a heterogeneous mixture of herbaceous species	36.5	58.4	5.1
8	Abandoned agricultural fields; land once tilled for crops on which native vegetation had re-established itself; community composition different from unit 7; primarily lacking in variety and abundance of perennial forbs	41.9	49.1	9.0

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Table 1. (continued)

Mapping Unit	Brief Description	% Soil Surface Cover		
		Plant Foliage	Plant Litter	Bare Soil
9	Other seeded grasslands; old seedings of crested wheatgrass, big bluegrass, and Russian wildrye (Elymus junceus) which have been infested with native herbaceous species	31.7	46.6	21.7
10	Native grasslands excluded from cultural practices or livestock use for long periods of time (± 30 years)	47.8	48.6	3.6
11	Unclassified land: ecotonal situations or extremely heterogeneous vegetation or other land classes not fitting any other vegetation grouping	--	--	--
12	Willow (Salix spp.) occurring along the flood plain of a stream. Herbaceous species occurring within the open areas between the shrub groups from either unit 14 or 15	98.0	1.0	1.0
13	Open water -- streams and beaver ponds of various depths and turbulence	--	--	--
14	Native bluegrass (Poa praetensis) meadows; species of sedge (Carex spp.) rush (Juncus spp.) and native clover (Trifolium spp.) ubiquitously scattered throughout the area.	85.0	12.7	2.5
15	Sedge/rush/bulrush (Scirpus spp.) meadows; normally occurring with standing water or seasonally ponded areas	94.7	5.3	0
16	Roads			
17	Bare soil (unstable gullies, alluvial fans)	--	--	--

Table 2. Spectral bands of data collection, Manitou Experimental Forest (M-19)

Detector	Spectral Band-- 10 Percent Power Points (micrometers)
Spectrometer (channel)	
1	0.398-0.431
2	0.423-0.456
3	0.446-0.475
4	0.458-0.487
5	0.478-0.508
6	0.492-0.536
7	0.514-0.558
8	0.538-0.593
9	0.566-0.638
10	0.604-0.700
11	0.656-0.775
12	0.725-0.920
Near Infrared	
1	1.0-1.4
2	1.5-1.8
3	2.0-2.6
Thermal Infrared	
1	4.5- 5.5
2	8.2-13.5

(2)   P-220 loaded with Ektachrome Infrared film, Type 8443, with a W15/CC30B filter package; and (3) KB-8 loaded with Ektachrome Infrared film, Type 8443, with a W15/CC50B filter package. The exposed film was subsequently used to assist in the selection of training samples for recognition processing.

Four diurnal timer periods were selected. The 0830, 1200 and 1600 (local sun time) missions were flown on July 28. A fourth mission was flown at 1000 local sun time on July 29. Four flight lines were flown in a general south to north direction at two altitudes: (1) 1,000 feet and (2) 3,000 feet above mean ground datum of 7,700 feet above mean sea level. Thus, a total of 32 data missions were flown.

All scanner data were recorded in analog form. Radio communication between the aircraft and ground crew using Forest Service FM radio equipment provided instant ground data for setting the airborne scanner reference levels.

Prevailing weather during the mission schedule was clear skies during the early morning with increasing cloud build-up during the day. Afternoon and evening thundershowers were frequent. Consequently, the morning imagery (0830 and 1000) was obtained under clear skies. The afternoon imagery (1200 and 1600) was flown under broken clouds. For these two missions, the aircraft circled until flight lines were relatively clear of cloud shadows. Some shadows were imaged along the flight lines however.

High Flight (Mission 139). On July 21, 1970, between 0924 and 0942 local sun time the NASA RB57F aircraft exposed various films at three small scales along a single flight line extending from near

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Pikes Peak on the south (lat. 38°55' N., long. 105°04' W.) to a point

east of Deckers on the north (lat. 39°17' N., long. 105°08' W.),

a distance of approximately 23 nautical miles. The Manitou Experi-

mental Forest Headquarters site was located approximately midway

along the flight line. The flight line was flown twice to assure

complete coverage. Film/filter/scale combinations exposed are

listed in Table 3. All cameras were set to obtain 60 percent forward

overlap for stereoscopic coverage.

Prevailing weather during the mission schedule was generally

clear with a few high, thin cirrus clouds along the flight line.

Continuous fog occurred to the east of the area near Colorado

Springs and the U. S. Air Force Academy. A slight cumulus build-up

was occurring to the west of the flight line area.

Communications between the ground crew and the airplane were not

available during the mission.

RESULTS AND DISCUSSION

Multispectral (M-19).

All processing of the multispectral data was done at the

University of Michigan's Willow Run Laboratories under master

contract NASA9-9784 and monitored by NASA, Manned Spacecraft Center,

TF-8. Research Engineers M. M. Spencer and F. J. Kreigler were the

prime data processors. In depth details of the processing procedures

are documented in the report, "Analysis and recognition processing of

multispectral scanner imagery of the Manitou Experimental Forest

site in Colorado" by M. M. Spencer, September, 1971 (#31560-80-L).

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Table 3. Film/filter/scale combinations exposed during Mission 139, NASA RB57F

Camera	Lens Focal Length	Film	Filter	Film Format	Scale
Zeiss	12 in. (300mm)	2443	W15	9 in. (230mm)	1: 53,000
RC-8	6 in. (150mm)	2443	W15	9 in. (230mm)	1:104,000
RC-8	6 in. (150mm)	SO-397	2E	9 in. (230mm)	1:104,000
Hasselblad	1½ in. (40mm)	SO-117	W15+CC30B	2.75 in. (70mm)	1:405,000
Hasselblad	1½ in. (40mm)	SO-117	W15	2.75 in. (70mm)	1:405,000
Hasselblad	1½ in. (40mm)	SO-168	2E	2.75 in. (70mm)	1:405,000
Hasselblad	1½ in. (40mm)	2402	W25	2.75 in. (70mm)	1:405,000
Hasselblad	1½ in. (40mm)	2402	W58	2.75 in. (70mm)	1:405,000
Hasselblad	1½ in. (40mm)	2424	W89B	2.75 in. (70mm)	1:405,000

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At this time, data from only one of the 32 data missions have been processed for multispectral recognition of native plant communities. These data were from flight line 1, flown at 3,000 feet above the terrain at 1000 hours local sun time on July 29, 1970 (Figure 3). This particular data mission was chosen for five primary reasons: (1) Video display of the preprocessed data from channel 10 (0.604 - 0.700 µm) indicated that this flight time and altitude might provide the best opportunity for the recognition processing, (2) cloud shadows noised the data at the 1200 and 1500 hours flight times, (3) the halo effect was particularly noticeable in the 1200 hours data and to some extent in the 1500 hours data, (4) environmental conditions prior to the early morning flight (heavy predawn rain) left target surfaces very wet and contributed to high relative humidity, both of which would contribute to abnormal radiance effects and (5) time and budgetary constraints precluded much additional data processing. In addition, most plant communities of interest were represented in this flight line and there was little variation in mean ground elevation (± 200 feet).

It became obvious in preprocessing review with the IROL engineers that some of our initial mapping units, to be used as recognition categories, were too generalized to provide a valid statistical recognition signature for any of the categories. These included mapping units 11, 13, 16 and 17 (Table 1). For example, category 11 (unclassified land) had no unifiable feature within the area and consequently statistical variation of training samples would result in a high order of misclassification.

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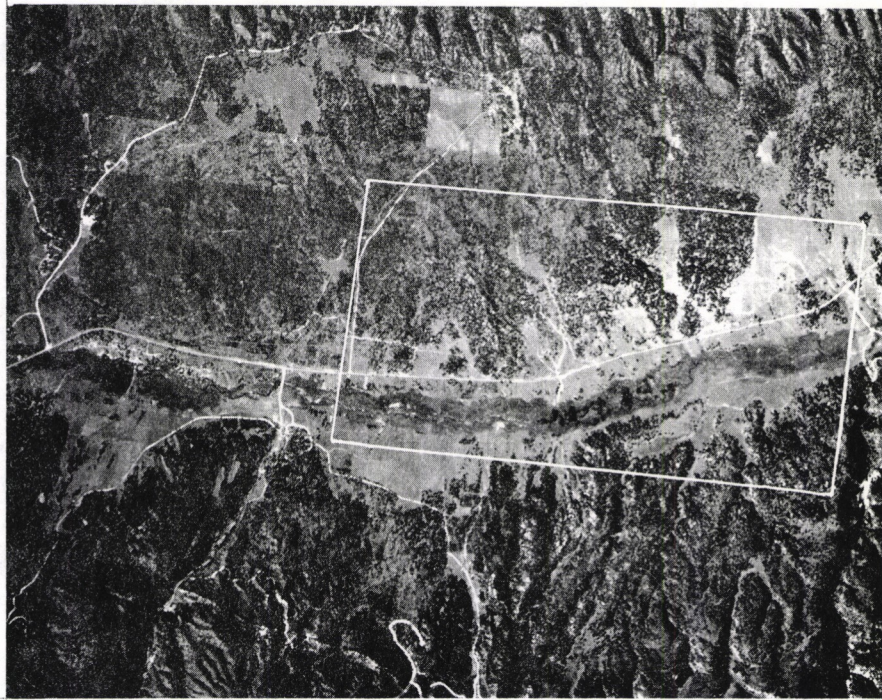
Figure 3   Area within the rectangle includes the analyzed scanner
coverage of a part of flight line 1 flown at 3,000 feet above the
terrain (1000 hours local sun time; 7/29/70). Training sample areas
for computer recognition can be located in this illustration by
referring to Figure 6. (See Table 1 for a description of these
units.)   The photo was made from an IR color transparency from the
NASA RB57F Mission 139; scale 1:53,000. At this photoscale, all
recognition categories can be interpreted visually.

Consequently, this category was eliminated from recognition processing.
Map unit 13 was also a heterogeneous unit for recognition purposes.
It included relative shallow and deep water in various degrees of
turbidity and included various amounts of hydrophyllic vegetation.
This unit was also eliminated from recognition processing. Map
unit 16 included both hard packed dirt and gravel roads as well
as an asphalt road. This unit was reduced to only the asphalt
road to provide orientation in the recognition map. Map unit 17
represented all kinds of bare soil areas; alluvial fans, bare
gullies and naturally occurring bare soil areas. The decision was
made to select training samples that could be identified in the
support aerial photographs and let the remainder of the bare soil
areas be classified by chance.

Another decision was made regarding mapping units 1 and 2.
Both these units represented ponderosa pine forest but one unit
(#1) had been recently logged and the other (#2) was unlogged.
Major differences between these two areas were the amount and
extent of tree foliage, the size and pattern of openings in the
forest canopy and the vegetation composition of the forest floor
within the openings in the forest canopy. To include each as an
entity, samples for recognition signatures would have to include
combined information from all these conditions. Consequently,
the variance in spectral statistical signatures would be high,
possibly leading to serious misclassification. Two alternatives

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were available: (1) Increase the sample size to reduce signature variance or (2) reclassify the map units (recognition categories) to a common denominator. We chose the latter alternative, in which a new unit or recognition category was defined with its spectral statistical signature characterized as dense ponderosa pine foliage, wherever it existed. The remaining areas, primarily openings in the tree crown canopy, could then possibly be classified as one of the grassland categories or not classified at all by the developed program. If the latter happened, it would indicate that these openings represented unique vegetational situations requiring specific spectral signature reference. The results of this reclassification are listed in Table 4.

A scan angle effect is present in all optical mechanical scanner data. This is to be expected since the view angle of the scanner mirror system for a discrete bit of data at an instant in time varies through the arc of the scanner field of view. Assuming that a target material had the same reflectance throughout the arc of the mirror system, the point of illumination is at the nadir, and the geometry of all components of the target material is perpendicular to the nadir, the scan angle effect would graphically illustrate a normal distribution curve. The apparent scene radiance for the target area for a scan line would be strongest at the point where the scanner view angle was simultaneously perpendicular to the

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Table 4. Revised list of recognition categories

Category No.
(Map Unit)   Brief Description

2T   Ponderosa pine forest

3   Dense natural ponderosa pine regeneration

4   Dense planted ponderosa pine regeneration

5   Seeded grassland (crested wheatgrass)

6   Seeded grassland (big bluegrass)

7   Native grasslands

8   Abandoned fields with native vegetation different
                        from 7

9   Other seeded rangeland

10   Other native rangelands, i.e., exclosures excluding
                        livestock grazing or areas manipulated by cultural
                        practices

12   Willow type vegetation

14   Native bluegrass meadows

15   Sedge/rush/bulrush meadows

16   Asphalt roads

17   Bare soil (alluvial fans, unstable gullies)

target and illumination source, tailing off to each end of the scan line. The data can then be easily normalized so that the scene radiance is uniform for the whole scan line. Assuming that this occurred for all categories to be classified along a flight path, the scene radiances and variances expressed in a straight-line relationship would provide a simple way to compare relative changes in radiance among spectral channels for recognition purposes.

The previously described condition would seldom occur since the probability of the scanner view angle being simultaneously perpendicular to the illumination source (the sun) and a natural target scene (a plant community of constant geometry) is nil. Therefore, a scan angle effect caused either by atmospheric effects and/or bidirectional effects must be expected. The atmospheric effects, caused by absorption and scattering of radiation by atmospheric haze, are influenced by scanner height above ground and are most prominent in the short visible wavelengths (Horvath, et al. 1970). We concluded that these effects were negligible since visibility was in excess of 100 miles at the time of the data mission and the flight altitude was only 3,000 feet above the terrain.

Bidirectional effects are common, however, and our data were analyzed assuming such effects were present. The bidirectional reflectance effect is the combined effect of variation in sun angle, scanner view angle, and the bidirectional reflectance properties of various types of surface objects.

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There was a significant scan angle effect in the scanner data
taken at 1000 hours on July 29, 1970, as identified by a technique
developed by Kreigler (1971). The aircraft was flying on a 348°
heading with a ground speed of 120 knots. This placed the antisolar
point ahead and to the west of any particular scan line. Figure 4
illustrates the scan angle effect from data plotted for three
categories registered in channel 5 (0.478-0.508 μm). Each point
on the curve represents the statistical mean value of a training
sample, each training sample consisting of a block of 100 resolution
data cells identified on the gray map. Two categories, ponderosa
pine forest (2T) and native grassland (7), were selected because
training areas for these units were scattered throughout the scan
line direction. One other category, seeded big bluegrass (6), was
used because training samples were located on each end of the scan
line, although a smooth curve was not developed. The smooth curves
represent only category 2T, the lower curve, and category 7, the
upper curve.

If recognition signatures for categories 2T and 7 were selected
from midpoints along the scan line, these mean values would not
compare to those on either end of the scan line, and there would be
high probability of category recognition confusion. For example,
the signature values for category 2T at the beginning of the scan
line do, in fact, overlap values for category 7 mear the end of the
scan line. Particular recognition confusion would result for a
category with mean signature values occurring between those of
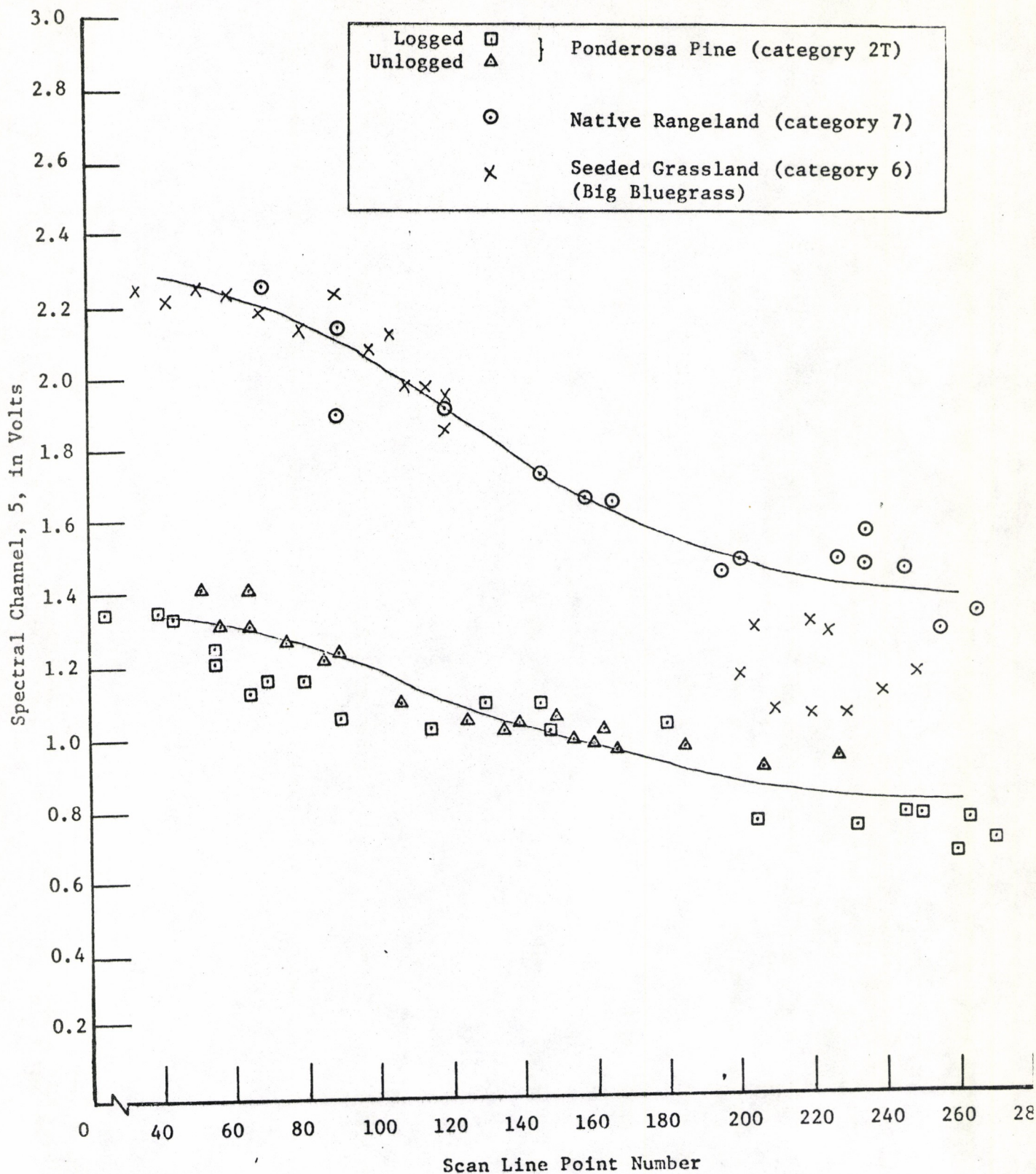
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Figure 4   The smooth curve representation of the polynomial scan angle functions for units 2T (ponderosa pine forest), and 7 (native range) from data in spectral channel 5 (0.478-0.508 μm). The points for seeded big bluegrass (unit 6) illustrate the relative radiance differences from the beginning and the end of the scan line.

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categories 2T and 7. This is exemplified by the plot of signature

values for category 6 at the high scan line numbers (Figure 4).

These training sets have the same mean values as category 7. If

this phenomenon occurred in all spectral channels, categories 2T

and 6 would not separate, even if they were spectrally dissimilar,

because of the scan angle effect. This emphasizes the importance

of eliminating the scan angle effect before processing the data for

recognition.

The scan angle effect was eliminated from our data using

transformation processes developed by Kreigler, et al. (1969).

Figure 5 illustrates the results of normalizing the data for the

three example categories in channel 5. The upper horizontal line

represents the transformed mean signature values for category 7.

The lower horizontal line represents the transformed mean signature

values for category 2T. The transformed training sample means

for category 6 have simply been identified.

The combined mean value of all training samples for category

2T was 1.02 volts corresponding to the voltage levels representing

apparent scene radiance. All mean values of the individual training

samples were within $\pm$ 0.1 volt. The mean signature value for category 7

was 1.78 volts. Only two of the 14 individual training sample mean

values did not occur within the $\pm$ 0.1 volt limit. These apparent

anomalous values could also be identified in the untransformed data.

The reasons for this could be associated with mislocation of those

particular training sample areas in the initial gray map printout

as related to actual ground position, or they could represent some

other recognition category. This has not yet been determined.
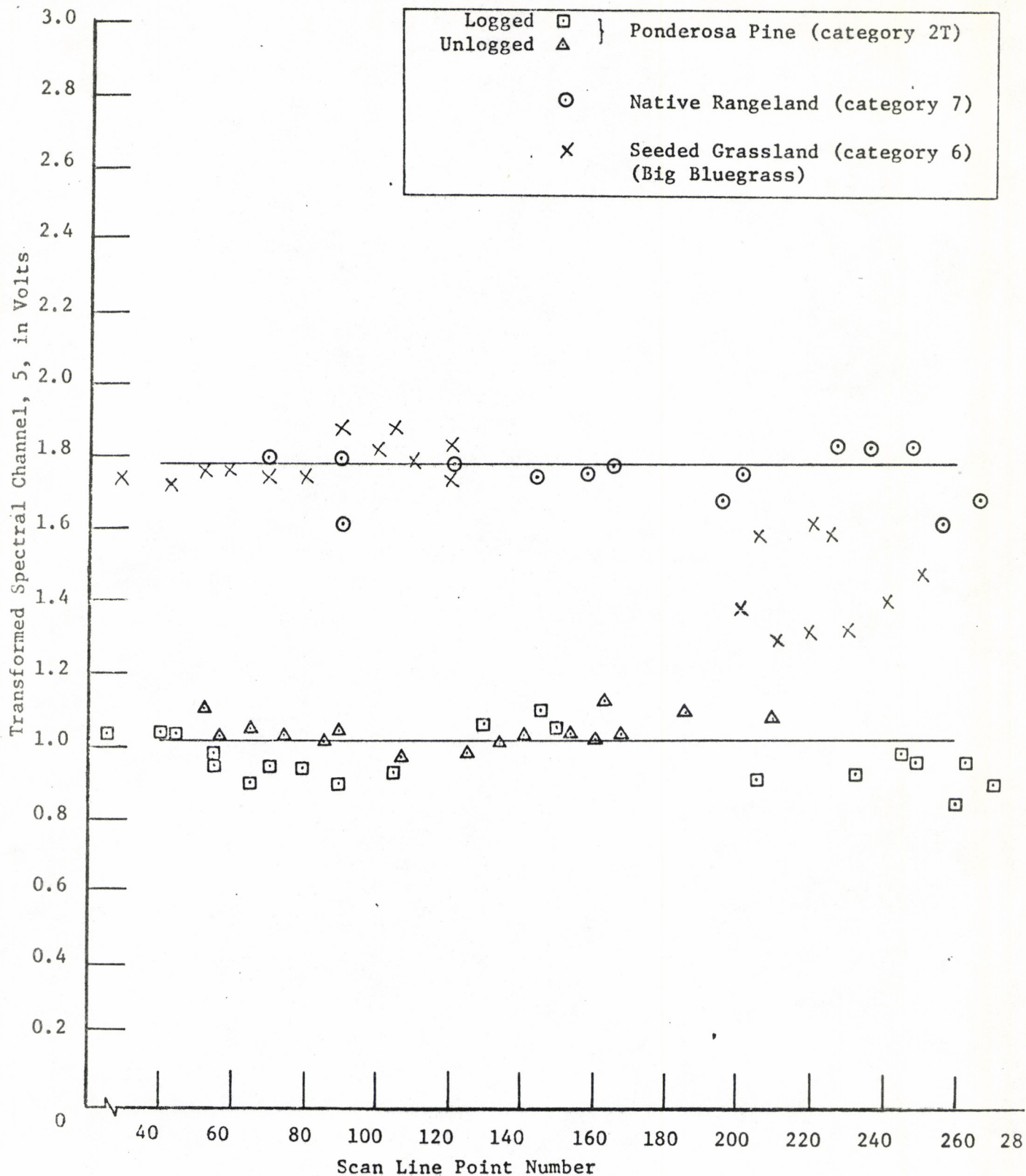
Figure 5   Normalized data from channel 5 (0.478-0.508 μm) with the scan angle effect eliminated. The point scatter for the big bluegrass seeding at the high scan line numbers indicates a heterogeneous population based on apparent radiance signals in this data channel.

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The relationship between category 6 and the other two categories used for an example was more easily discerned after the data were transformed for channel 5. As in the untransformed data, the big bluegrass seedings (category 6) near the beginning of the scan line show image signatures not dissimilar from the native range (category 7). This was true also for the data from channel 1 (0.398-0.431 μm). However, the data from what was classified "big bluegrass seeding" near the end of the scan line did separate, generally, from both of the other recognition categories. This indicates, at least for one channel of data, that the three plant communities will separate on the basis of relative differences in apparent radiance.

The foregoing discussion illustrates the importance of considering preprocessing multispectral scanner data to account for apparent radiance variances caused by scan angle effects. Although specifically related to only three recognition categories and one channel of data, similar relationships among all categories among all data channels should be expected. Without preprocessing, the probability of misclassification, especially for plant community types within a generalized community system, would likely be high.

Signature selection to represent recognition categories was relatively simple using preprocessed data, providing that the training sample elements were homogeneous. This was true for categories 16 (asphalt road) and 17 (bare soil areas). Hence only one signature was used to represent these categories. One signature was used for category 14 (native bluegrass meadow) since this area was so small that we could locate only one training sample area on the gray map

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with high assurance that the area did in fact represent that category. The statistical signatures computed from the training areas for category 3 (natural ponderosa pine regeneration) and category 4 (artificial pine regeneration) were so similar, that it was arbitrary as to which one was used. Consequently, only one training area with its statistical signature was needed for these categories.

Category 2T (ponderosa pine forest) had many training sample areas since it was used to determine the scan angle effect. Consequently, the digital program COMSCL was used to determine the signature value for this category. This program converges the means and variances of at least two individual signatures and computes a new mean and variance to be used as a new element of the recognition signature.

For the grassland categories 5 through 10 (Table 4), a much more tedious procedure was needed to obtain the signature to represent each category. Even after the data had been preprocessed to eliminate the scan angle effect, there was wide variation both within and among category signature values. This could be related to two factors: (1) The inability to precisely locate, on the gray map used to determine training sets, the exact position of a specific training area. Even on the video display of the channel 10 preprocessed data from which the gray map was generated, it was difficult to discern the boundaries between some of the categories as we had originally mapped them. This was especially true among

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categories 6, 7, 8 and 10, and categories 5 and 9. When linear dimen-
sions such as fence lines or seeded area boundaries were evident,
this was not so difficult. However, when such evidence was not
apparent, or even when differences among community categories could
be seen in the mapping photographs, the mental transcription from
photograph to gray map location was difficult and possibly in
error. (2) The second factor causing the wide variation of grassland
signature values, one which may be more important to the problem of
grassland community discrimination, is related to convex mixtures
of amount and kind of herbage cover, plant litter and bare soil
represented in the equivalent resolution element. Even though
the data in Table 1 identify an amount of these three ground cover
characteristics for each mapped unit or recognition category,
considerable variation occurred among samples used to generate these
statistics. For example, the range of vegetation cover in category
7 (native range) among the subsample units was 29 to 45 percent.
This range on an individual plot basis, corresponding to the ground
equivalent resolution element, was from 20 to 45 percent within an
individual subsample unit. Although the ground sampling technique
was adequate to describe the mapped units (recognition categories),
especially when plant species composition was considered, serious
apparent anomalous information occurred in the scanner data.

Unfortunately, the specific plot locations used to obtain these data were not positively located either on the ground or the mapping photographs. It might be possible to use data on hand from the various category subsample units to analyze the scanner data for effects of varying amounts of ground cover components, in order to determine the effects of these on apparent radiance. Additional research is needed, however, in which various mixtures of the ground cover components, in a natural condition, can be precisely located in the multispectral data and analyzed for the effects of these mixtures on apparent radiance.

Signature selection for the grassland categories was based on a method which used the probabilities of misclassification as criteria to determine similarity among units. With this routine, statistical parameters (mean, variance, covariance) for all channels were considered simultaneously for computing pairwise probabilities of misclassification. This term does not mean the distinction between the two possibilities of error in the normal procedure for testing statistical hypotheses. Rather, it involved testing many distributions by a likelihood ratio test in which each distribution was tested pairwise with all other distributions and the resulting Type II error from each test was summed. Thus, the distribution with the largest total of Type II errors was the distribution to represent a specific classification category. Figure 6 shows the locations of training areas selected by this process.
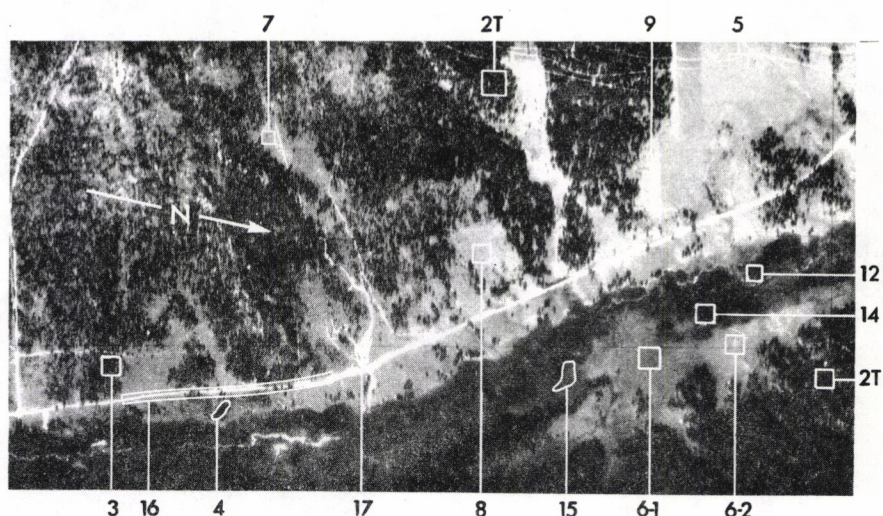
Legend

2T	Ponderosa pine forest
3	Dense natural ponderosa pine regeneration
4	Dense planted ponderosa pine regeneration
5	Seeded grassland (crested wheatgrass)
6	Seeded grassland (big bluegrass)
7	Native grasslands
8	Abandoned field with native vegetation different from 7
9	Other seeded rangeland
10	Other native rangelands, i.e. exclosures excluding live- stock grazing or areas manipulated by cultural practices
12	Willow type vegetation
14	Native bluegrass meadows
15	Sedge/rush/bulrush meadows
16	Asphalt roads
17	Bare soil (Alluvial fans, unstable gullies)

Figure 6   Location of various components of the training area, identified by category (map unit) number.

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Channel optimization for the classification problem was also based on the average probability of misclassification in which the six best channels were chosen on an ordered selection scheme. The process assumed that the signatures represented a Gaussian distribution of random variables, an assumption which thus far has been good for similar data examined (Heller, et al. 1970). A pairwise classification scheme was used in which, if there were M categories (recognition units), then there were M(M-1) probabilities of misclassification computed and averaged. For example, the probability of misclassification of each pair of materials was the probability of misclassifying material M2 as material M1. The end result, during which each entry was weighted, provided an average pairwise probability of misclassification and identified the best channel for classifying the categories previously defined. This ordered selection next combined the first channel with each of the remaining n-1 channels and picked the best combination of two channels. The process was continued until the best combination of channels was identified. The results of the ordered selection scheme, which was made in order to determine the spectral channels to use for the recognition processing, is shown in Table 5.

Six channels were selected for recognition processing. The channel selection procedure was stopped at this number because the addition of other channels indicated minimum improvement in recognition accuracy. For example, adding the effects of channel 6 indicated an increase in accuracy of classification by only approximately 11 percent. This was deemed acceptable for this problem (the classification of

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Table 5. Spectral channels ordered for classification of eight herbaceous plant communities, three ponderosa pine forest communities, one shrub community, and two nonvegetated categories

Spectrometer Channel No.	Spectral Band (μm)	APPM[1]	Percent Accuracy Increase
10	0.604-0.700	0.0736	
12	0.725-0.920	0.0386	48
5	0.478-0.508	0.0290	25
9	0.566-0.638	0.0240	17
7	0.514-0.558	0.0209	13
6	0.492-0.536	0.0185	11

[1] Average pairwise probability of misclassification

plant communities) because a minimum level of accuracy for Agricultural
Crop Census has been suggested at about 85 to 90 percent (Anderson 1971).
However, one of the potential uses of pattern recognition using scanner
data would be to monitor human-induced change in vegetation over time.
These changes are frequently subtle but important and therefore would
require something better than 10 to 15 percent accuracy. Problems re-
lated to accuracy improvement were previously discussed in relation to on-
the-ground community classification and training set selection.

For the final recognition processing, the decision rule to
classify each data point used a likelihood ratio test. This test
was applied to each data point among all selected spectral channels.
The test simultaneously compared the information content of each
data point for category recognition and assigned the data point
to a particular category when the following n-1 ratio tests were
simultaneously satisfied:

$$\frac{f(M_i)}{f(M_j)} > 1$$

where:

$f(M_i)$ is the multivariate Gaussian probability density
function for category M_i, and

$f(M_j)$ is the multivariate Gaussian probability density
function for category M_j

The recognition processing results obtained from the digital
computer are shown in Figure 7, a photograph of the color digital
recognition map. This area represents a unit of terrain approximately
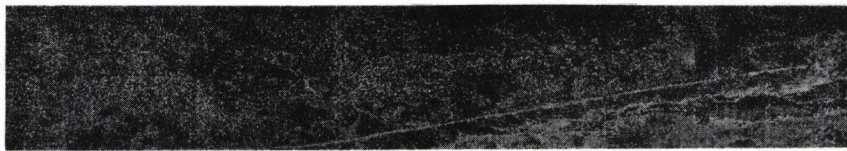
Figure 7   Color digital recognition map from six normalized data channels.
The training area map (Figure 6) and IR color map (Figure 3) will aid in
interpretation of the results. Most serious mixing of category recognition
was between the big bluegrass seeding (Category 6), near top right corner
of the map, and the three classes of native rangeland (Categories 7, 8 and 10).

2 miles long and 1 mile wide. The color/symbol coding which was used is listed in Table 6. The exact symbol coding is not recognizable in the photograph due to scale reduction from the original digital color map. However, if the reader makes a correspondence between color shades and the location of training areas (Figure 6), this will aid in interpreting the map.

Generalized plant communities were acceptably isolated. These included the forested areas (green), areas with hydrophyllic vegetation (black), and areas of upland herbaceous vegetation (red, blue and purple). This was not totally unexpected however, since others have reported similar results (Smedes, et al. 1971, Heller, et al. 1970). On-the-ground conditions of these units were very dissimilar and produced high contrast in apparent radiance signals.

However, problems existed in community classification by computer recognition processing for the upland herbaceous plant communities (categories 5-10). Even though intense preprocessing of the data was done, a large amount of misclassification occurred. For example, the bluegrass seeding in the northwest portion of the area was erroneously identified with the abandoned fields, with native vegetation, and with parts of category 7 (native range). Likewise, the native range and abandoned fields categories were mixed severely in some areas.

This does not mean that multispectral spectrometer data with the adjunct preprocessing techniques cannot be used for identifying and classifying specific plant community types within a generalized

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Table 6. Color/symbol codes for digital color recognition map

Category[1]	Unit	Color				
		Green	Red	Blue	Black	Purple
2T	Ponderosa pine forest	✍				
3	Natural pine regeneration	θ				
4	Artificial pine regeneration	*				
5	Crested wheatgrass seeding			✍		
6-1	Seeded big bluegrass with sweetclover		*			
6-2	Seeded big bluegrass with conglomerate forbs			*		
7	Native range					6
8	Abandoned fields different from #7		✍			
9	Other seeded rangeland			=		
12	Willow communities				✍	
14	Native bluegrass meadows				*	
15	Sedge/rush/bulrush meadows	=				
16	Road (Asphalt)				.	
17	Bare soil		=			

Not Classified   Blank spots in the map

[1] Original categories 1 and 2 combined to ponderosa pine forest. Category 6 was separated into two units at high scan line numbers due to severe mixing with other categories, especially #9. 6-1 represents now big bluegrass seeding contaminated with yellow sweetclover (Melilotus officinalis); 6-2 represents big bluegrass seeding contaminated with numerous other herbaceous species. Category 6 at low scan line numbers and category 10 confounded with category 8 and additional research is needed to find out if these categories can be separated. Original categories 11 and 13 were not included in the processing.

herbaceous system. Rather it means we must be more discretely selective in choosing training sample areas representative of the community types selected. For example, the native range (category 7) areas identified by the recognition processing was correctly identified but not all native range areas were classified as native range. Those areas correctly identified consisted of plant communities with a composition primarily of vigorous stands of Arizona fescue and mountain muhly and little bare soil surface showing through the community canopy. Other areas not classified as native range but mixed with category 8 (abandoned fields) had considerably less herbaceous cover, less litter cover on the ground and more exposed bare soil surface. Similar conditions existed between the relatively pure big bluegrass seeding (low scan line numbers) and the more sparcely vegetated native range areas.

It may be that the relative radiance of herbaceous vegetation per se is not sufficiently contrasting to provide discrete separation. If this is the case, more consideration must be aligned to the combined relative amounts of vegetation cover, litter cover and bare soil surface which may provide the information needed for acceptable recognition processing. More research needs to be done on this aspect of the problem. This can be done with some of the spectral and corresponding ground truth data in hand. However, controlled experiments need to be initiated whereby the effective scanner ground resolution element can be isolated in the multispectral data with absolute information about the three ground cover characteristics. In

addition, we need to know more about the ground scene radiance of various combinations of ground cover characteristics to determine the effects of these characteristics, together with community speciation, on effective scene radiance. This should be done using a field-going spectrometer calibrated to the band pass characteristics of the airborne multispectral scanner.

The normalized data from the six channels identified for digital processing were also processed through the Michigan Spectral Processing and Recognition Computer. The SPARC system accepts analog data and presents the results in analog form which is more easily interpreted than the digital map. Since the SPARC system can accept only data about eight recognition categories and we processed 14 recognition categories using six data channels, two separate operations were performed on the SPARC. The results of this processing are illustrated in Figure 8. The color codes are identified in Table 7. The relationships between the digital and analog processing in relation to known ground conditions were the same.

There is some confusion in interpreting the SPARC map as compared to the digital map. For example, on the SPARC map, seeded crested wheatgrass is identified as yellow and the other seeded grassland (category 9) is identified as dark green. Interpreting the digital map, point by point, shows some mixing of these two categories in the crested wheatgrass area, but the major portions of the data points in fact
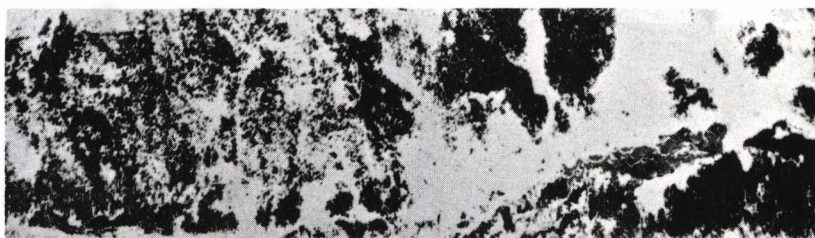
(a)
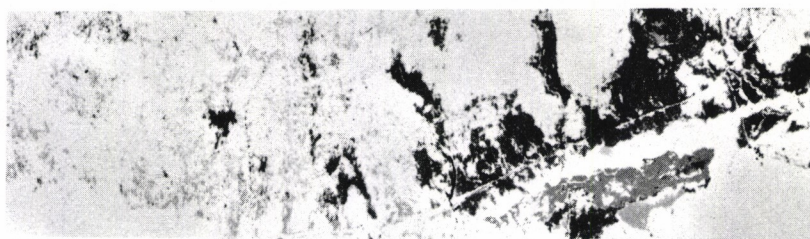
(b)

Figure 8   Color recognition maps from SPARC processing using the six
normalized data channels (channels 5, 6, 7, 9, 10, 12). Refer to Table 7
for the color coding of these maps.

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Table 7. Color coding for SPARC recognition map for Figures 8(a) and 8(b)

| ------------------ Figure 8(a) ---------------- | | | ------------------ Figure 8(b) ------------------ | | |
Category	Unit	Color	Category	Unit	Color
2T, 3, 4	All ponderosa pine	Green	6-1	Seeded big bluegrass with sweetclover	Dark Blue
12	Willow communities	Orange	6-2	Seeded big bluegrass with conglomerate forbs	Light Blue
14	Native bluegrass meadows	Purple			
			12	Willow communities	Orange
6-1	Seeded big bluegrass with sweetclover	Dark Blue	9	Other seeded rangeland	Dark Green
15	Sedge/rush/bulrush meadow	Red	5	Crested wheatgrass seeding	Yellow
			8	Abandoned fields with vegetation different from any of the above	Red
			7	Native rangeland	Purple
			17	Bare soil	Black

represent the crested wheatgrass area. The SPARC readout identifies

this area primarily as other seeded grassland. The reason for this

crossover is not known now, but available evidence indicates that

interpretation of the digital map may provide more discrete data

about the individual plant community types. A similar relationship

existed in SPARC classification of categories 6-2 and 7. Many

small areas in the south of the SPARC map were classified as

category 6-2 when they should have been category 7. The digital

map again identified a mixing of these two categories in the area

but the major portion of the data points were identified as native

range (category 7).

The utility of developing a multispectral processing technique

for native vegetation should be obvious. An important concern about

management of native vegetation relates to changes in vegetation over

time and determining what caused these changes. Since the multispectral

scanner (and peripheral equipment) records and stores bits of informa-

tion about a small piece of landscape, depending on the resolution

capabilities of the scanner system, any change in that piece of landscape

theoretically would be identified by a change in apparent radiance in subse-

quent scanner data. This assumes that discrete limits of the information

stored, that is the mean relative radiance levels with variances that

are discrete for specific plant communities, can be identified. The

percentage of data points representing a kind of plant community

can be computed (Table 8) and any change in these relative values

can be determined using sequential imagery. This would then represent

Table 8. Percentage and number of digitized imagery points
recognized according to category from the digital
recognition processing

Category	Percentage of Points	Number of Points
2T	19.8	45,099
3	13.3	30,294
4	9.6	21,866
5	2.0	4,555
6-1	4.7	10,705
6-2	5.0	11,389
7	9.2	20,955
8	13.4	30,521
9	2.9	6,605
12	2.6	5,922
14	1.0	2,278
15	1.2	2,733
16	1.2	2,733
17	0.6	1,367
Not Recognized	13.5	30,749
Totals	100.0	227,771

a change in area comprising a specific community type. Theoretically, this technique would provide more accurate information than photo interpretation only since interpreter error would be minimized. The concept needs substantial additional research, first to identify the minimum level of integrity with which the recognition processing can classify plant communities, and then (tested over time) to determine the repeatability of the technique.

High Flight (Mission 139)

The color photographs, both color infrared and normal color, were interpreted for plant community classification using the 1:8,000-scale color infrared photographs as "ground truth." The three black-and-white Hasselblad transparencies were to be used for multispectral combining. The hypothesis is that this technique would yield more information about community classification than would be obtained through independent use of color or black-and-white transparencies. Due to lack of ready access to a color combining system, this part of the experiment is not yet completed.

The three very small-scale (1:405,000) Hasselblad color photographs are illustrated in Figure 9. The color film (SO-168 with a 2E filter) was quite uniformly exposed although dark corners were evident. It had relatively good color balance in the lighter areas to provide for accurate color reproduction. However, it was generally underexposed which provided some difficulty for interpretation. The color infrared (SO-117 with a 15 filter) was slightly underexposed and nonuniform due apparently to the hotspot phenomenon.

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Figure 9(a) RB57F Hasselblad coverage (scale 1:222,000 enlarged
from 1:405,000) of the Manitou Experimental Forest (Site 242)
SO-168 with 2E filter. Nonuniform exposure was common, probably
due to hotspot phenomena.
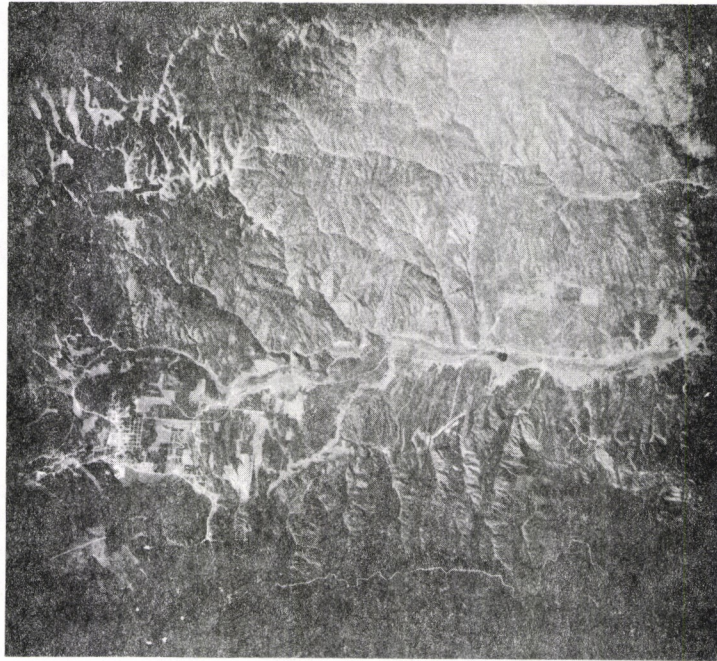
(b)
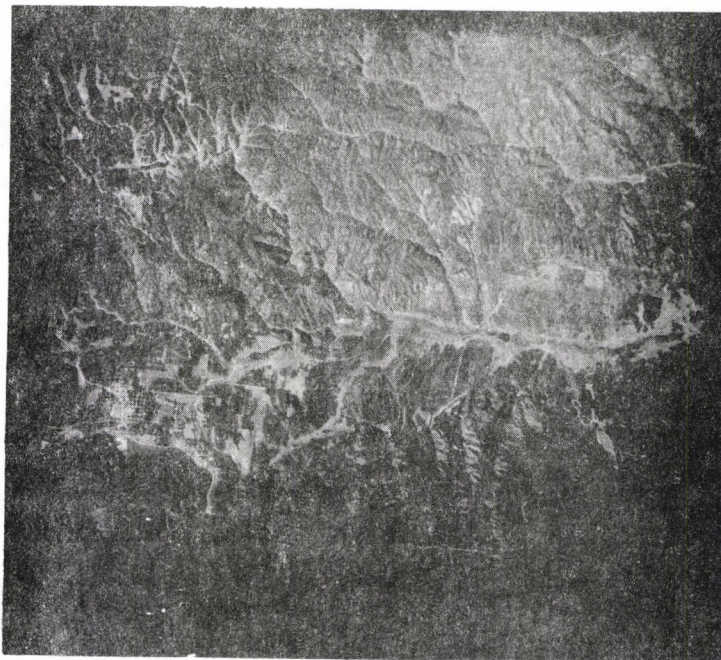
(c)

Figure 9(b) (c)   RB57F Hasselblad coverage (scale 1:222,000 enlarged from 1:405,000) of the Manitou Experimental Forest (Site 242).   (b) SO-117 with Wratten 15 filter, (c) SO-117 with Wratten 15+CC30B filter pack. Nonuniform exposure was common, probably due to hotspot phenomena.

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The other color infrared film (SO-117 with a 15+CC30B filter) is sharp
and clear, better than the other two films, but still with dark spots
around the edges and in the corners, due possibly again to the hotspot
phenomenon.

As might be expected, only generalized vegetation types could
be positively identified using the very small-scale transparencies.
This was especially true for the color (SO-168 with 2E filter).
With this film type, only five primary mapping units were determinant
(see Table 1 for descriptions). These included: (1) Recently logged
ponderosa pine (unit 1); (2) mature ponderosa pine (unit 2); (3) meadow
type vegetation (which includes mapping units 12, 14 and 15); (4) native
or native/seeded grassland mixtures (units 7, 8, 9 and 10); and (5) seeded
crested wheatgrass (unit 5). The seeded big bluegrass (unit 6) and pon-
derosa pine regeneration (units 3 and 4) could not be identified although
film resolution in relation to unit size was of sufficient quality to
potentially allow identification. The discrete ground differences did
not resolve in the very small-scale color photographs.

Both color infrared films at the same very small scale proved
to have more information content than the color film. In the timbered
areas, some differences in understory vegetation were quite clearly
discernible using 4X stereo viewing. This was especially true in the
small drainageways where soils are slightly heavier, soil moisture
was available longer to plants and where consequently, plant growth
was more luxuriant than in associated areas. Also there were discernible
differences among the meadow type communities that were not visible in

the color transparencies. Larger areas of willow (unit 12) could be isolated by color differences by stereo interpretation. In some cases, the native bluegrass meadow (unit 14) and sedge/rush/bulrush (unit 15) could be discerned although commission errors were frequent. The native grassland communities as defined in this study could not be discriminated on this very small-scale photography. Comparing the two infrared color films, the SO-117 with a 15+CC30B filter may have a slight margin over the SO-117 with a 15 filter for community classification. This may have been due more to exposure variances than potential latent information, however.

Community classification and mapping with the very small-scale photographs is inadvisable except for generalized plant communities, i.e. forested areas, grassland areas and meadow areas. Although community differences were observed within these units, the mapping units would have to include community complexes due to the very small photographic scale. Larger-scale photographs are needed to determine in more detail the size and structure of the plant community inclusions.

Color (SO-397 with a 2E filter) and color infrared (2443 with a 15 filter) films were simultaneously exposed in RC-8 cameras at a scale of 1:104,000. The color film was underexposed, apparently because of hotspotting (Figure 10). The color infrared film (Figure 1) also had nonuniform exposure but in other respects, was generally good. Color contrast and balance were satisfactory especially in the immediate vicinity of the Experimental Forest area.

Figure 10   RC-8, 150mm color photography (SO-397 with 2E filter) taken at
at a scale of 1:104,000. The exposure was nonuniform and most of the area
was underexposed.

Even at this larger scale, as compared to the Hasselblad imagery, the color film had limited value for community classification except for discrimination among general community systems. The forest types, grassland types and meadow types, in general, were discernible but specific ecosystems within these units could not be consistently identified. Some of the seeded areas (map units 5 and 6) could be located by association but primarily by linear dimensions of fence lines creating systematic patterns. Interpretive commission errors (between the seeded areas and other grasslands) were high, based on color contrasts.

There was a significant information gain using the RC-8 color infrared photographs (scale 1:104,000) for community classification, especially the meadow type vegetation. The willow communities (unit 12), were easily interpreted; many of the areas for type locations of the native bluegrass meadows (unit 14) and sedge/rush/bulrush meadows (unit 15) were identified. The seeded pasture areas were interpreted primarily on the basis of linear dimensions of the fields. However, color differences of the crested wheatgrass seeding (unit 5) had sufficient color contrast so that this type, in fact, represented a unit class unlike all others in the photography. The seeded big bluegrass (unit 6) was so similar in color to much of the native range (unit 7) that interpretive commission and omission errors were high. A similar problem existed in recognition processing of the multispectral scanner imagery.

The 1:53,000-scale color infrared photographs (film Type 2443 with a 15 filter) will be of prime value for refining multistage sampling techniques (Figure 3). Although these photographs were not uniformly

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exposed, the color contrasts were good and details of the forested areas,
grassland areas, urban developments and hydrologic features were distinct
and clear. Considerable detail was interpretable within the forested
areas, especially the recently logged area (unit 1). Although dif-
ferences in type locations of herbaceous systems in this unit were very
subtle in the photographs, areas where soil/water relations were more
favorable to plant growth, at the time when the photographs were exposed,
were identifiable. These were located primarily in drainage depressions.

The meadow type communities (units 12, 14 and 15) were easily inter-
preted at this photoscale. Although all three would probably be included
as a single mapping unit using this scale of photography, the area of
each could be accurately determined by point sampling or planimetry.
This information would then be used in probability multistage sampling
with smaller-scale photographs to determine the areal extent of the
community systems.

Misinterpretation of the seeded grasslands versus native range-
lands was still serious in the 1:53,000-scale photographs exposed at
the one time (July 21) during the summer growing season. This time was
chosen because it appeared to offer the best single time possibility of
optimizing ground differences among the community types determined by
phenological relationships. The single time hypothesis was also
based on a potential operational procedure in which photo data gather-
ing was presumed to be feasible only once during the year. Obviously,
this cannot be done if an investigator is concerned about subtle but
real differences among community types similar to those described for

this study. Our previous work as well as that of other researchers
has defined the need for multiseasonal photography for plant community
classification and species identification. We hope to define how one
might more succinctly overcome this problem, especially working with
small-scale photographs and gross resolution imagery with our ERTS
experiment; this will be done by working cooperatively with the Forest
Service Forest Remote Sensing Project. We need additional small- and
very small-scale photographs obtained seasonally before we can define
how best to map and classify plant communities similar to those at
the Manitou test site. On the basis of our data so far, color
infrared photographs at photoscales around 1:50,000 will provide
an intermediate sampling stage to classify and quantify community
systems as we ground-identified them at Manitou. Photoscales at
approximately 1:100,000 appear to provide minimum information gain
before obtaining suborbital (1:400,000) or orbital (1:2+ million)
data. This is not unlike results we obtained from our work with
Apollo 9 information (Driscoll and Francis 1970).

SECTION II
REMOTE MEASURES OF HERBACEOUS STANDING CROP
PROCEDURES

An ultimate analysis of aerial or space photographs would include
a determination of the herbaceous standing crop in specified plant
communities. This could be considered an end product for some manage-
ment decisions. This information would be extremely useful for evaluat-
ing and monitoring changes in energy balances of the vegetational
component of ecosystems which would be directly related to changes

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in productivity.

The details of this experiment were explained in a previous report (Driscoll and Francis 1970). Basically, ground truth consisted of simulating six levels of standing crop on 3x3-meter square plots by cutting, to equal herbage height, increments ranging from 0 to 100 percent herbage removal. The treatments were replicated four times in a big bluegrass seeding at the Manitou test site. Standing crop after herbage removal was estimated by double sampling with a hetero-dyne meter, an electronic device which senses mass within an array of probes (Neal and Neal, 1965).

Aerial photographs were flown at two scales -- 1:563 and 1:3,855 -- at the peak of the growing season in mid-August. This was done with the Forest Service Aero Commander using two 70mm Maurer cameras, one loaded with Anscochrome D-200 film and one with Type 8443 color infrared. All ground measurements were made within a week of the photo mission.

The color infrared photos were used in conjunction with a GAF microdensitometer (MDT) to provide image density differences among the various treatments. This film type was chosen because visual inter-pretation indicated that it provided more discriminatory evidence of differences among standing crop levels than color film. The MDT was programmed to scan with an effective circular aperture of $416 \mu^2$ with a green filter (Wratten 93).

Scan lines were run perpendicularly to seeded drill rows to avoid possible measurements of only vegetation type or of nonvegetated areas between the drill rows (Figure 11). Nine random starts per imaged
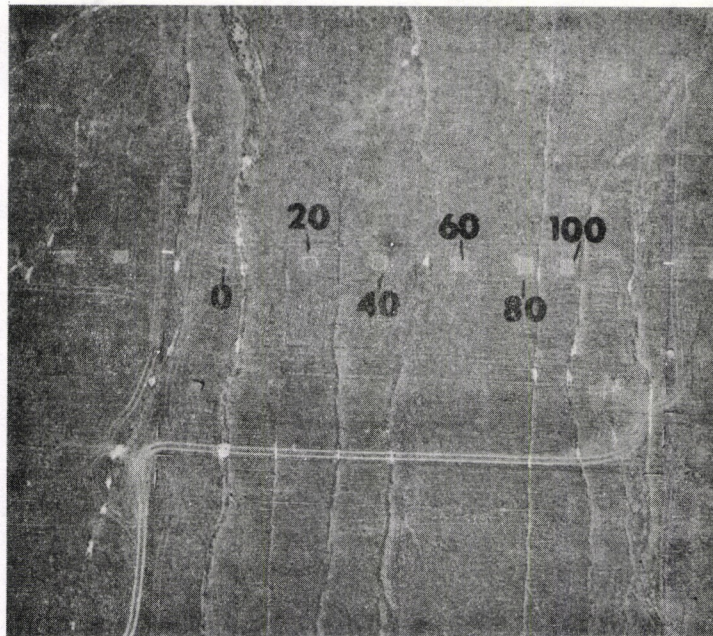
Figure 11   Visual and image optical density comparisons in a color
infrared photography (1:3,855) of various levels of herbaceous standing
crop in scale 1:2070 enlarged from a big bluegrass pasture indicate dif-
ferences among levels of standing crop. The regression relationship
between herbaceous green standing crop or its corresponding harvested
dry weight to photo image density is explained by the linear function
$y = a + b(x)$.

plots were used for the 1:563 photos; five were selected for the 1:3,855 photos. The data from the strip chart readouts were digitized by an Auto-trol digitizer.

RESULTS AND DISCUSSION

The digitized data and image density data were analyzed by regression and correlation. Green standing herbage and corresponding harvested dry weight were each regressed as dependent variables (y) to the photo image density (x).

If a correlation coefficient (r) of 0.80 is established as an acceptable level of accuracy, the image density derived from both scales of photography provides a valid estimate of either green standing herbage or harvested dry weight (Table 9). In all cases, the correlation coefficient is high and significant (P = 0.01) indicating a strong relationship between image density values and amount of biomass. The "best" relationship occurs between image density and harvested dry weight (r = 0.87) using the 1:563 photoscale and can be expressed as a simple linear function:

$$y = a + b(x) \quad \text{where:}$$

y = standing crop production (dry weight)

a = -151.72

b = 62.61

x = image density

However, since a possible operational application of this technique may not allow dry weight determinations, the green standing crop/image

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Table 9. Coefficients of regression (b), correlation (r) and determination (r^2) of image density values for green vegetation expressed on a corresponding harvested dry weight basis; color infrared photoscales 1:563 and 1:3,855

| | -------------- Green Weight ----------------- | | | --------------- Dry Weight ----------------- | | |
Photoscale	Regression Coefficient (b)	Correlation Coefficient (r)	Coefficient of Determination (r^2)	Regression Coefficient (b)	Correlation Coefficient (r)	Coefficient of Determination (r^2)
1:563	115.64	0.85 **	0.72	62.61	0.87 **	0.75
1:3,855	122.97	0.81 **	0.66	63.98	0.80 **	0.64

** Highly significant (P = 0.01)

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density relationship might be more practical. In this case, an estimate of green herbaceous standing crop can be determined by the simple linear equation:

$$y = a + b(x) \text{ where:}$$
$$y = \text{standing crop production (green weight)}$$
$$a = -281.31$$
$$b = 115.64$$
$$x = \text{image density}$$

We need to test this technique with native herbaceous plant communities. The plant species component of these systems is much more heterogeneous than the monospecific stand of big bluegrass. If the technique can be developed for native communities, it will provide one more data source for multiple sampling procedures to apply to either space or high-flight photography for determining kind, extent, and characteristics of plant communities over extensive areas.

Results of this experiment are being prepared in more detail for publication in a technical journal.

MICRODENSITOMETRY FOR PLANT COMMUNITIES AND COMPONENTS

PROCEDURES

The hypothesis of this experiment was that plant species and communities could be identified by the optical density of their film images. At or near three of our test locations, Black Mesa, Manitou and McCoy, ground data were collected to insure positive identification of plant species, communities and other features in the aerial photographs. This procedure provided a 1:1 assignment of film image to absolute ground truth. The ground procedures are discussed by Francis (1970).

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A Mauer KB-8 camera was used to obtain photographs with Ektachrome

Infrared Aero, Type 8443 (color infrared) film with a Wratten 12 filter.

The camera was mounted in an Aero Commander 500 B aircraft which flew

at heights from 400 to 15,000 feet above the terrain. The film type

was selected because previous exploratory research identified it as

the most useful for plant species and community identification by photo

interpretation.

To report these findings, we considered the dimension of the

plant community or component for which optical density was measured

and related this to what estimated near-optimum photographic scale

might be required. These surface features were then grouped, based on

scale requirements and results discussed within these groups. In this

study two scale groups existed, based on the system reported by Heller

(1970).

Very small scale -- Selected scales were 1:139,000 and 1:135,000

to include generalized plant communities such as a forest, a

grassland or a shrub type. Landscapes around Blue Mesa Reservoir

near the Black Mesa area, and the Manitou area, were used.

Large scale -- We selected scales of 1:800, 1:1,100 and 1:2,700 to

be used for smaller plant community components. For example,

at Black Mesa components were range sites, at Manitou they were

cultural treatments on a small area, and at McCoy individual

tree and shrub species.

A General Aniline and Film Corporation microdensitometer was used

with a Honeywell "Electronik" Strip Chart Recorder attached to generate

the scan lines. Trial scans were made with the microdensitometer to

determine the best effective aperture, color filter and film scan

speed combinations to discriminate the various plant community images.

Measured and visual comparisons established the fact that a round

aperture, when used with a green filter, provided the best opportunity

for plant community and community component discrimination based on

image density differences. The round aperture was used because it

coincided more closely with the geometry of the plant communities

or species components being considered. The green filter indicated

greater optical density spread between communities and components.

Magnification for effective aperture size depended on the community

or components to be discriminated.

RESULTS AND DISCUSSION

Very Small Scale

Figure 12 shows the mean optical density values and one standard

deviation from the mean obtained from microdensitometer scan lines using

color infrared film and a green filter (Wratten 93) of the Blue Mesa

Reservoir area. The coefficient of variation provides comparison of

variability about the different means. The mean density value of the

water body (4.06) separates it from all plant communities and components

including spruce-fir forest which had a mean density of 3.45. Other

features show some overlap of image density at one standard deviation,

although that of aspen forest (mean 3.11) and rock and soil (mean 3.16)

separate from the spruce-fir forest and the water body.

There was a greater range in optical density values of the three

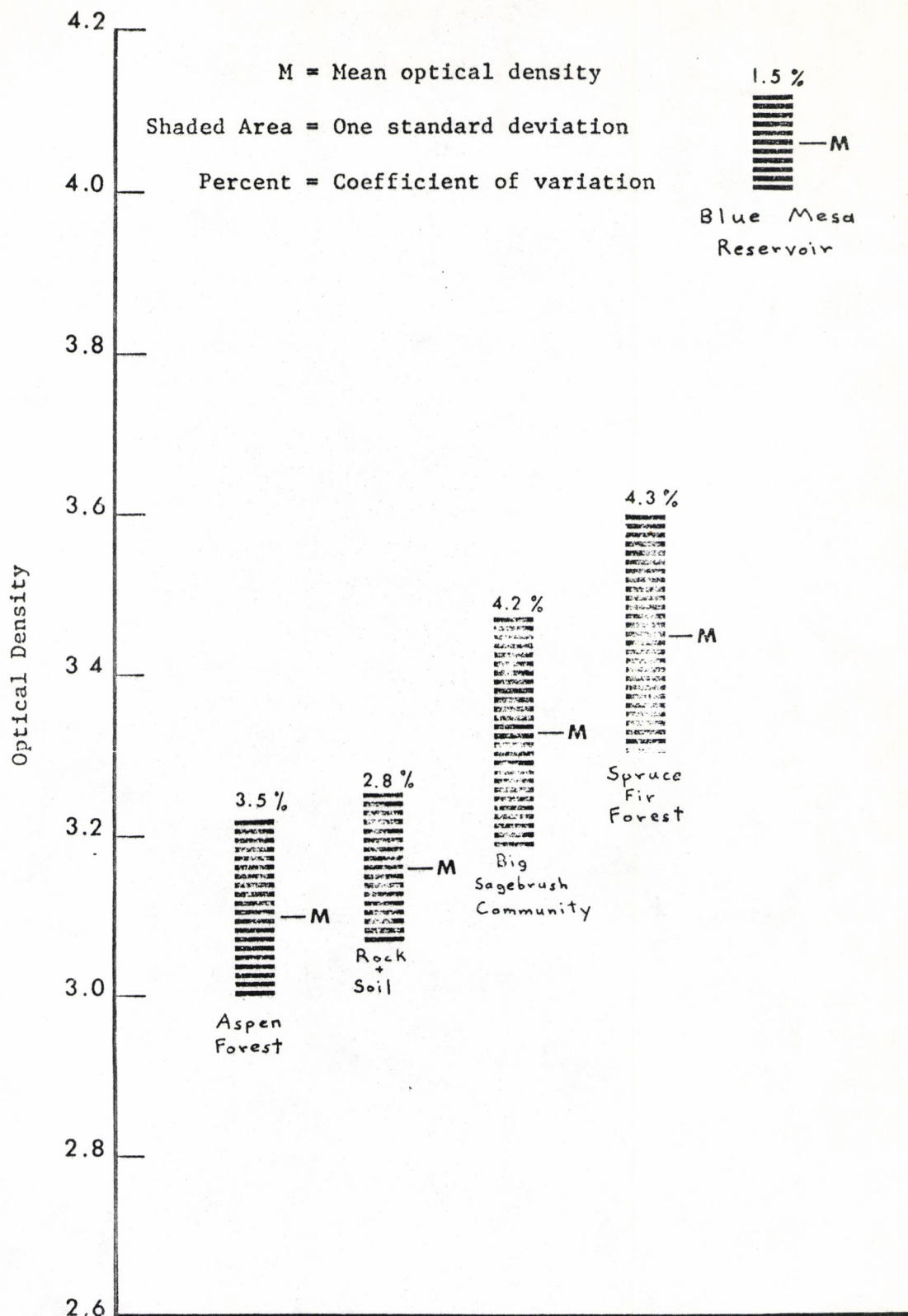plant communities as compared to the water body, as identified by the

Figure 12   Optical film density through a green filter (Wratten 93) of three plant communities, rock and soil and Blue Mesa Reservoir, west of Gunnison, Colorado; 30 September 1968; scale 1:139,000, color infrared -- 8443.

larger coefficients of variation. This would be expected especially for
a spruce-fir forest because it is a very heterogeneous plant community
while the water body is homogeneous.

The images of four plant communities at Manitou were compared
for optical density. Mean optical density for the two grassland
communities (3.09 and 3.25) were similar but were discretely less
than the two forest communities (3.66 and 3.73) (Figure 13). The co-
efficient of variation in density values was less for the grasslands,
(2.9 percent and 0.6 percent), especially the seeded area, than the
pine forest communities. The density variation of the big bluegrass
area was sufficiently narrow that mean optical density separated
it from native grassland at one standard deviation. The coefficient
of variation in mean optical density for the ponderosa pine forest
(5.7 percent and 6.4 percent) was greater than the two forest types at
the Blue Mesa Reservoir location (Figure 12). This is because the
pine forest is usually a more heterogeneous plant community than
the spruce-fir or aspen forest. A pine forest often has natural and
cleared openings and more sun and shadow contrast which results in a
greater range in density values.

Large Scale

Three microdensitometry trials were made to separate, by optical
density, plant communities and components on large-scale photography.
At Manitou, considering the four cultural treatments, the results
were not encouraging (Figure 14). The range in mean density values
among all treatments was only 0.11 value points (2.71 for untreated
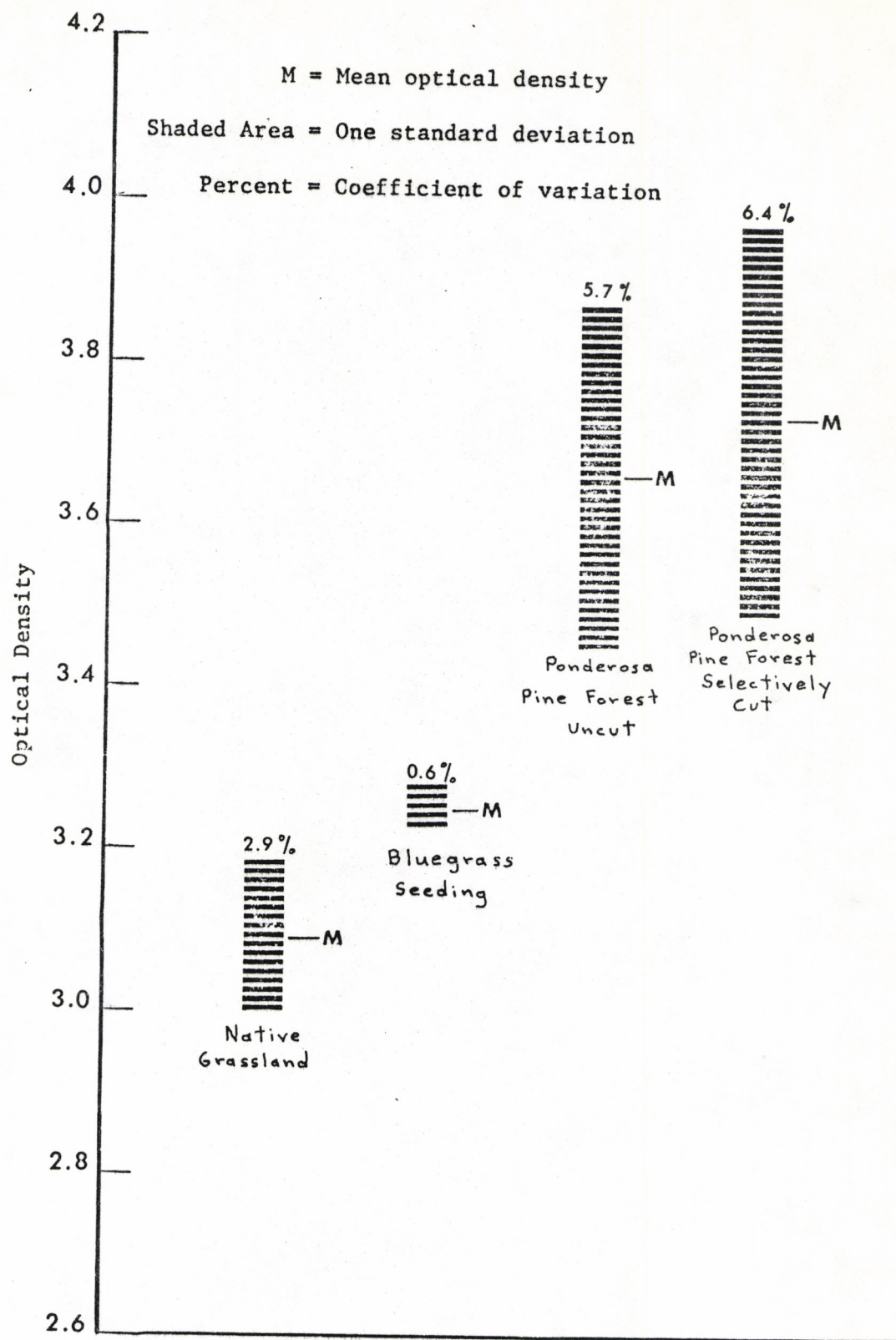
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Figure 13   Optical film density through a green filter (Wratten 93)
of two grassland communities and two forest communities. Manitou
Experimental Forest, Colorado; 1 October 1968; scale 1:135,000;
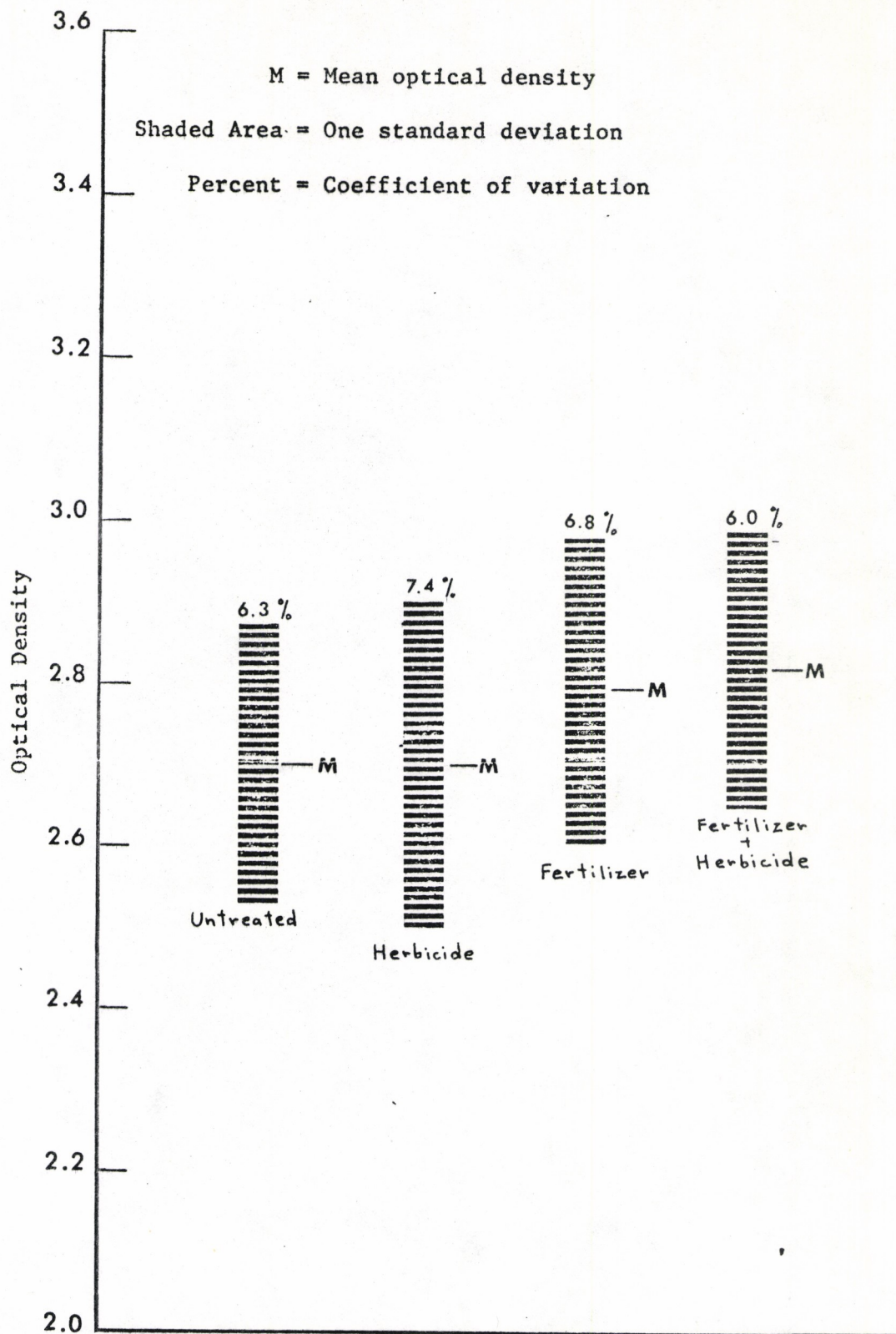color infrared -- 8443.

Figure 14   Optical film density through a green filter (Wratten 93) of four cultural treatments. Native grassland community, Manitou Experimental Forest, Colorado; 8 August 1968; scale 1:2,700; color infrared -- 8443.

areas to 2.82 for an area treated with fertilizer on herbicides).

Coefficients of variation varied from 6.3 percent to 7.4 percent.

Therefore, treatment effects could not be discriminated at one stan-

dard deviation (0.20) by image density although visual differences

were apparent in the photographs. Apparently these visible differ-

ences had little effect on optical density.

A second trial was made with large-scale color infrared photo-

graphs at Black Mesa to determine if optical densities of photographic

images of two range sites were different (Figure 15). Results showed

a higher density value for the more productive site (3.20) as compared

to the less productive site (2.95). However, considerable variation

in density values (coefficients of variation were 10.3 percent and

7.5 percent respectively) caused severe overlap in optical density

at one standard deviation and therefore, the sites could not be

discriminated.

A third trial with large-scale photography was made of two tree

species, four shrub species, and bare soil at the McCoy test site to

determine how well individual species and bare soil could be separated

by image optical density. Mean image density values varied from 2.50 for

soild to 3.68 for mountain mahogany (Figure 16). The soil value at one

standard deviation was sufficiently different from all six plant species

to provide confident identification. This was due both to low mean

density and a low standard deviation (0.02) and coefficient of variation

(0.8 percent) which indicated a homogeneous community component. The two

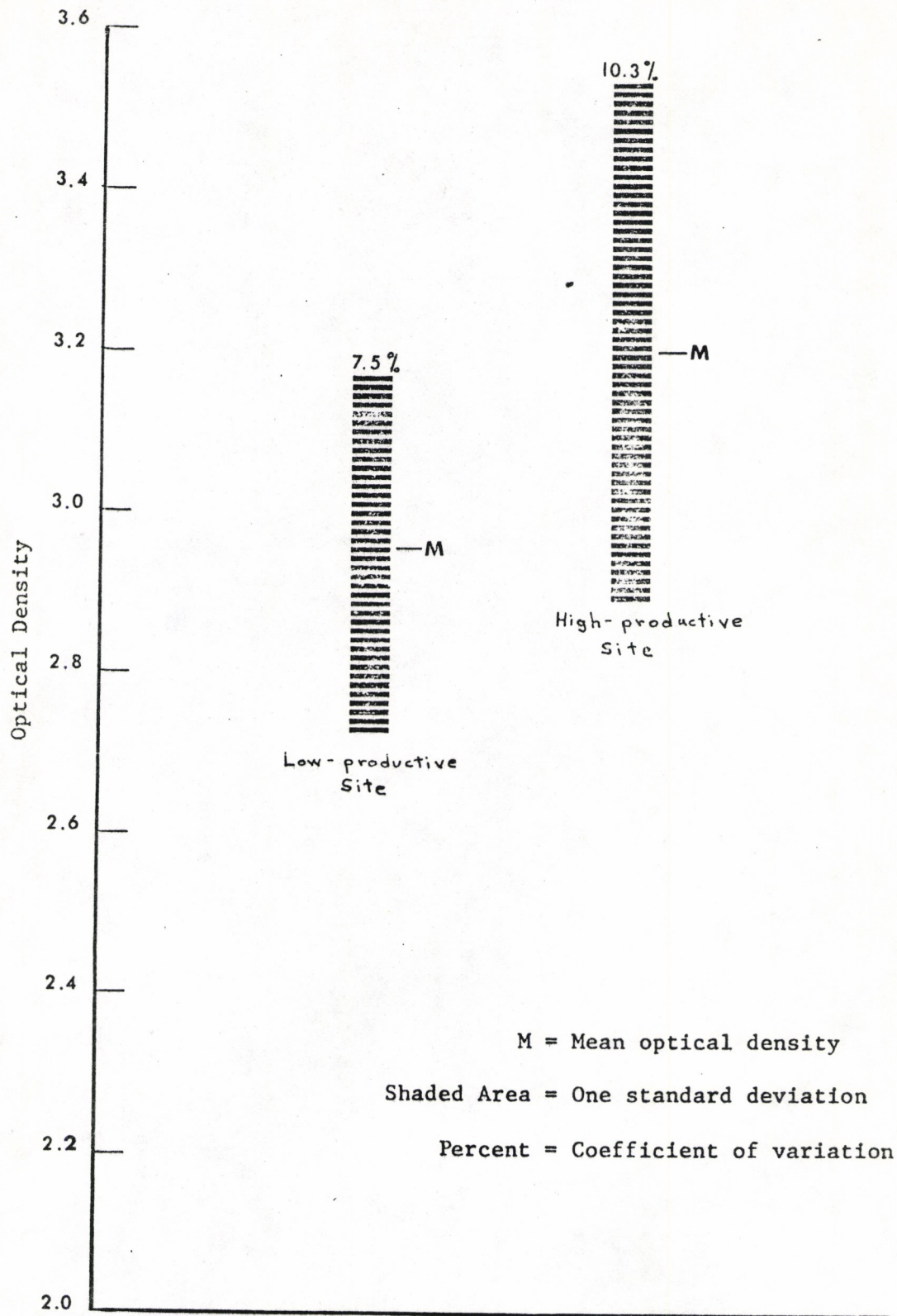species of sagebrush (mean densities of 2.77 and 2.80) separated very

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Figure 15 Optical film density through a green filter (Wratten 93) of two grassland sites. Black Mesa Colorado, 7 August 1968, scale 1:800, color infrared -- 8443.
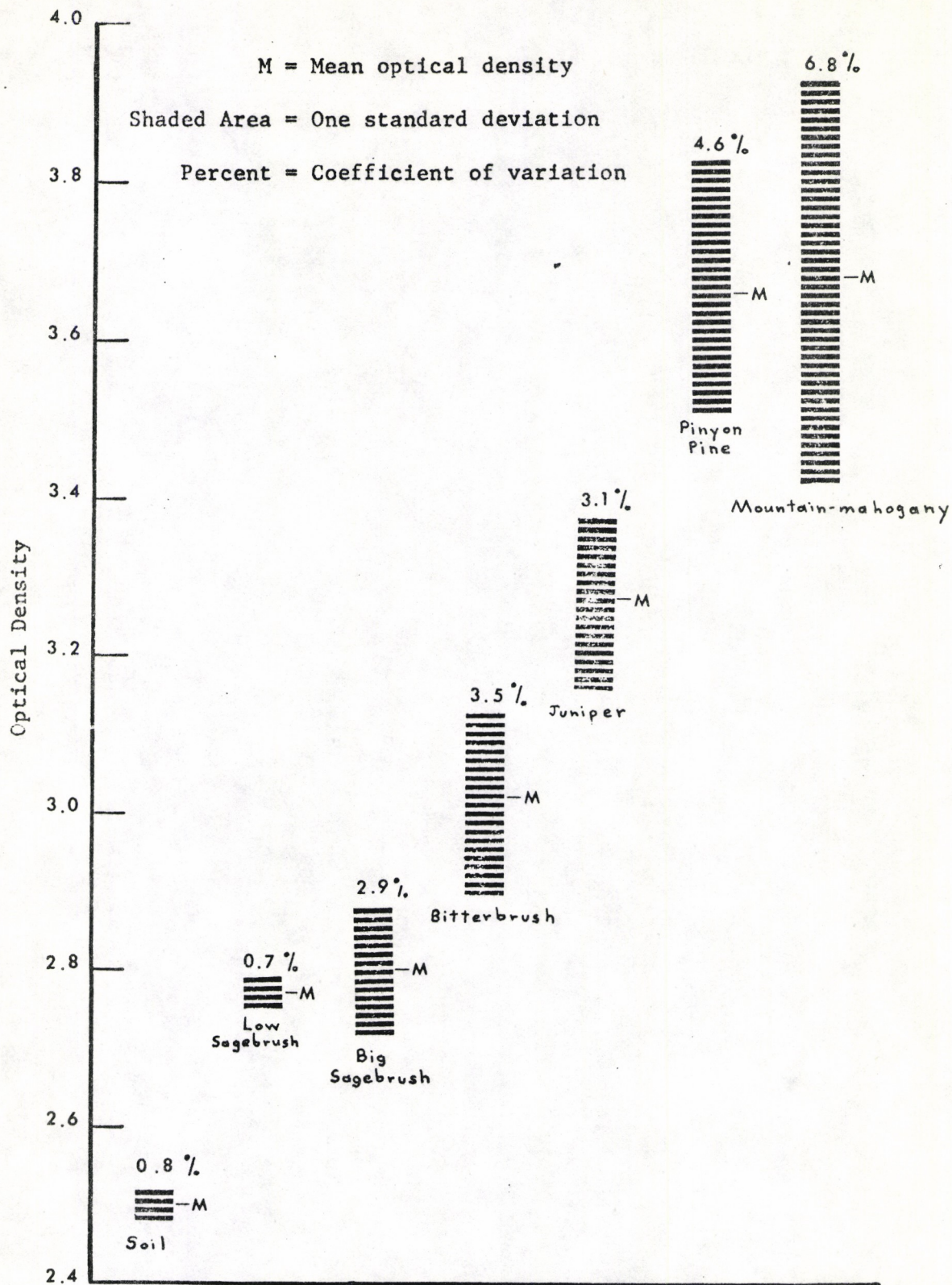
Figure 16   Optical film density through a green filter (Wratten 93) of two trees, four shrub species, and soil. McCoy, Colorado, 6 August 1968, scale 1:1,100, color infrared -- 8443.

well from the four other species (mean optical densities of 3.17 or more), but not from each other. However, by image color and shape these two species are easy to correctly identify nearly 100 percent of the time (Driscoll and Francis 1970).

Based on optical transmission as a measure of density of film images examined in this study, the microdensitometer separated some, but not all, plant communities and their components identified by manual photo interpretation. Independently considering all five test locations -- a total of 27 optical density tests -- seven complete separations at one standard deviation occurred at three locations (Figures 12, 13 and 16). In addition, 10 partial separations occurred at the same three locations. Partial separation occurred when a plant community or component separated from some, but not all of the others at a particular location.

Minimum opportunity for target separation based on optical density occurred most often within a single plant community even though site variability or treatment effects were visible to a photo interpreter (Figures 13, 14 and 15). These phenomena are unexplained at this time.

One of the most obvious characteristics that aids in optical density separation is related to homogeneity of the plant community or component. This was obvious as identified by density values of the water body (Figure 12), bluegrass seeding (Figure 13) and soil (Figure 16) as compared to other plant communities in the photographic imagery.

Aldrich (1971) reported mean optical density values for 11 land

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classifications from 2.44 (plowed field) to 3.87 (pine forest) --
a range of 1.43. His microdensitometer tests (with a red filter)
were with very small-scale (1:2,430,000) Apollo 9 color infrared
film exposed in early spring. Comparing his test with our two very
small-scale tests (Blue Mesa Reservoir -- 1:139,00, and Manitou --
1:135,000) where nine plant communities and components were examined,
mean optical density ranged from 3.09 (native grassland, October 1)
to 4.06 (a reservoir, September 30) -- a range of 0.97. For the six
tree and shrub species and soil at McCoy (scale 1:1,100) the range
in mean optical density was 1.18; from 2.50 (soil) to 3.68 (mountain
mahogany). This indicates that there is value for using microdensi-
tometry for automated interpretation on very small- as well as very
large-scale photographs.

Plant community or component size is not an important element
in density discrimination assuming appropriate scale of photography.
This research identified both success and failure for both community
components such as individual small shrubs and generalized vegetation
types. Optical density separation may be acceptable on large-scale
or small-scale photography depending on the particular optical film
densities being measured in a given mosaic of landscape features.

These results are encouraging, but additional research is needed
to more positively identify seasonal and photoscale effects on image
optical density. In some of the cases of poor optical density separation,
acceptable discrimination by manual photo interpretation is possible (Dris-
coll and Francis 1970). This suggests that bringing other spectral char-
acters into a system could be a way of assembling an efficient remote

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inventory and monitoring system utilizing more than optical film density alone.

Steiner (1970), working with 11 crop classification in Switzerland suggested a two-dimensional system utilizing time as well as the spectral dimension (in this case optical density on large-scale panchromatic aerial photographs). This concept could be useful and increase the likelihood of correct differentiation between wildland plant communities as well as individual plant species.

Steiner measured optical density of the 11 crops from photographs obtained at 10-day intervals from early April into August. Naturally the crop communities were more homogeneous and therefore easier to separate than most of our wildland plant communities (the average optical density standard deviation for crops was 0.04). The data matrix was subjected to a linear discriminate analysis. The result was 100 percent correct crop classification.

Steiner pointed out that such repeated observations would be especially suitable from an orbiting survey satellite. A broad outline for automation of crop surveys from an orbiting satellite was also given. This would have application for wildplant communities which are of interest. Anderson (1971) suggests that such a system should have a minimum level of accuracy of about 85 to 90 percent which is comparable to the current land use enumeration for the Census of Agriculture.

How addition of the time dimension could conceivably aid in plant community separation is identified in Figure 12. At the late September date the yellowing aspen forest community, although separate from the spruce-fir forest, is undifferentiated from the rock-soil component

and to some extent the big sagebrush community. Procurement of photography after leaf fall or when the leaves were in various green states of development would undoubtedly change the optical density of the aspen forest. By combining, through use of discriminate analysis, optical density from several different phenological times, the aspen forest would likely separate from the other community types or nonvegetated areas in the photo image.

Similarly, mountain mahogany (Figure 16) should separate, by optical density, from pinyon pine with large-scale photography secured at other date(s) because one is an evergreen and the other deciduous with obvious different density values at other times of the year.

Results of this experiment are being prepared in more detail for publication in a technical journal.

SUMMARY

This past year, we added emphasis to our research to determine how analyses and recognition processing of multispectral scanner imagery could be used for discrimination of native and culturally affected plant communities. We have also devoted significant effort to data analysis and summarization for reporting our research results in technical journals. We spent considerable time working with R. C. Heller (P.I.) and colleagues in preparing for our portion of the ERTS experiment. For details, see their 1971 annual progress report.

Multispectral (M-19).

1. Serious scan-angle effects were identified in the multispectral scanner data taken at 1000 hours on July 29, 1970. By plotting the apparent scene radiance of a specific category (vegetation classification unit) the effect was determined to be a third-order polynomial function. The effect is believed to have been caused by bidirectional reflectance which is the combined effect of variation in sun angle, scanner view angle and the bidirectional reflectance properties of the specific scene. Atmospheric attenuation was believed not to be a serious influence on the scanner data since visibility was in excess of 100 miles at the time of the data mission and the flight altitude was only 3,000 feet above the terrain.

2. Preprocessing was performed on the data to remove the scan angle effect using techniques developed by University of Michigan IROL research engineers. Theoretically, with the scan angle effect removed, only one computer training sample per recognition category is required for further recognition processing. We followed this procedure.

3. Channel optimization for recognizing 12 vegetation and two nonvegetation categories representing mapping units was based on the average probability of misclassification in which the six best channels were chosen on an ordered selection scheme. These were:

Channel No.	Spectral Band (μm)
10	0.604-0.700
12	0.725-0.920

Channel No.	Spectral Band (µm)
5	0.478-0.508
9	0.566-0.638
7	0.514-0.558
6	0.492-0.536

4. The recognition processing results provided acceptable discrimination of generalized plant communities. These included: (1) ponderosa pine forested areas, (2) upland herbaceous vegetation, (3) hydrophyllic herbaceous vegetation.

5. Serious problems still exist in classification of plant community systems within the generalized herbaceous community type. Seeded crested wheatgrass was satisfactorily classified. However, seeded big bluegrass was mixed seriously with native range which was in turn confused in the computer processing for abandoned fields with native vegetation significantly different from native range.

6. Additional processing needs to be done to attempt to segregate the misclassified vegetation systems. This would involve more discrete selection of representative training samples. It would also involve new research in which the relative radiance of mixtures of vegetation, bare soild, and plant litter cover on the soil were considered as classificatory evidence of community types.

High Flight (Mission 139)

1. Generally, photographs generated from this mission were good in all respects except exposure. In all cases, the imagery was slightly underexposed and was not uniform throughout any single frame. This was possibly due to hotspot phenomena.

2. Color infrared photographs (Type 2443 with a Wratten 15 filter or SO-117 with a Wratten 15 filter) provided more information about plant community identification than color film (SO-397 or SO-168 each with a 2E filter) at all photoscales (1:53,000, 1:104,000 and 1:405,000). The addition of a CC30B to the SO-117+15 for very small-scale photographs (1:405,000) added no significant interpretive qualities.

3. The 1:53,000 color infrared photographs were valuable for refining multistage sampling for plant community extent and composition. We have not yet completed this aspect of our research.

4. These conclusions are based on only one high-flight mission. They need to be tested against other data obtained at different seasons of the year and integrated into a discriminate function analytical procedure to optimize native plant community classification.

Remote Measures of Herbaceous Standing Crop

1. Image optical density measured with a microdensitometer was highly correlated with either green herbaceous standing crop of seeded big bluegrass or its corresponding oven dry weight using color infrared (Type 8443 + Wratten 12 filter) positive transparencies at photoscales of 1:563 or 1:3,855.

2. The relationship can be expressed as a simple linear function $(y = a + b(x))$. In all cases the correlation coefficient (r) was highly significant (P = 0.01) and greater than 0.80.

3. These results identify how the system can be used to remotely determine herbage production of a seeded grass stand. We now need to test the system for native herbaceous communities considering both

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season of photography and different scales. This would provide a way for synoptic sampling of standing crop at any specific point in time.

Microdensitometry for Plant Communities and Components

1. Varied results were obtained when using the microdensitometer for automatic classification of plant communities and components. In general, the greater the homogeneity of the image of interest, the greater the possibility of automated interpretation by microdensitometry.

2. Seeded grasslands, bare soil or rock areas, and generalized plant communities identify acceptably well by optical density measurements through a green (Wratten 93) filter on small-scale (1:135,000 - 1:139,000) color infrared (Type 8443 with Wratten 12) transparencies obtained in the fall.

3. Individual species, range sites, or site treatment effects were not identified at an acceptable level of accuracy using the imagery available.

4. By taking advantage of the seasonal aspects of plant communities in relation to changing image characteristics and using linear discriminate analyses, one might find it possible to develop an analytical system using microdensitometry to obtain near 100 percent correct community classification.

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APPENDIX I

The following is a list of Forest Service, U. S. Department of Agriculture, personnel who contributed to this study and represent a major salary contribution to it:

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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Richard S. Driscoll, Principal Plant Ecologist and Project Leader

Richard E. Francis, Associate Range Scientist

*Ricky E. Morgan, Range Technician

Meredith J. Morris, Principal Biometrician

*H. Dennison Parker, Jr., Range Technician

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*Thomas C. Watson, Range Technician

*Temporary assistants

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In addition, the COLORADO GAME, FISH AND PARKS DIVISION, specifically R. B. Gill, Research Biologist, contributed to this research.